AN ENGINEERING GEOLOGICAL INVESTIGATION OF GROUND SUBSIDENCE ABOVE THE HUNTLY EAST MINE AREA

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of the requirements for the Degree
of
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in the
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by

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THESIS with 3 separate maps in back pocket.

" The process of coal mining, as indeed the mining of any stratified mineral, is inevitably followed by some degree of sinking of the superjacent strata and consequently of the surface"

Royal Commission on Mining Subsidence,
Second and Final Report,
London, 1927.

ABSTRACT

Ground subsidence above the Huntly East Mine at the N.Z.E.D. Hostel has affected an area of approximately seven hectares with measured settlements of over 800mm. Extensive damage was suffered by most buildings and services of the hostel complex (a $2M development) with remedial measures being estimated at approximately $450,000.

To determine the cause(s) and mechanism(s) of the subsidence, site and laboratory investigations were undertaken. Site investigations included core and wash drilling, geophysical borehole logging, dutch cone penetrometer soundings plus piezometer installation and minotoring. Laboratory investigations included one dimensional consolidation and permeability testing, SEM fabric studies, XRD and chemical tests for clay mineralogy, and determinations of Atterberg Limits and grain size distributions.

The mine overburden geology at the site consists of a 35 to 60m thick sequence of mudstones and coal seams of the Te Kuiti Group (Eocene to Oligocene), and overlain by a 50 to 70m thick succession of saturated sands, silts and gravels of the Tauranga Group (Pliocene to Holocene). Within the Tauranga Group three aquifers are present. Drilling, combined with laboratory testing has defined a 4 to 10 metre thick, laterally extensive, highly compressible ignimbritic silt aquitard above the lowest aquifer.

The engineering geological model considered most likely to explain the subsidence is mine roof collapse causing void migration to near the top of the Te Kuiti Group sequence resulting in drainage and depressurising of aquifers at the base of the Tauranga Group. Aquifer depressurisation is considered likely to cause consolidation within both the aquifer and aquitards associated with it.

Back-analyses of the dewatering consolidation model in terms of both magnitude and rates of settlement are consistent with observed values. A finite difference numerical analysis was developed for estimations of settlement rates.

Further field verification of the dewatering consolidation model requires monitoring of piezometers in areas of potential ground movement and inspection of workings under subsided ground.

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NOTATIONS

a_v	coefficient of compressibility
C	constant of compressibility
C_c	compression index
c_v	coefficient of consolidation
e	void ratio
k	coefficient of permeability
m_v	coefficient of volume compressibility
n	porosity
N	newton
Pa	pascal
q_c	cone resistance
f_s	sleeve friction
w	water content
w_l	liquid limit
w_p	plastic limit
ρ	density of soil
ρ_s	density of solid particles
ρ_w	density of water
ρ_{sat}	density of saturated soil material
ρ_b	buoyant density
ρ_d	density of dry soil material

$\bar{\sigma}_c$	preconsolidation pressure
$\bar{\sigma}$	effective intergranular stress
σ	total stress
μ	pore water pressure (neutral stress)

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CHAPTER I

INTRODUCTION

1.1 Subsidence at Huntly

Ground movement at the N.Z.E.D. (New Zealand Electricity Division) Hostel, Burke Place, Huntly was first noticed in early January, 1983. Within two months the area affected had extended to five hectares with settlements[1] up to 550mm. In April 1983 the affected area had enlarged to approximately seven hectares with maximum settlements of 800mm.

The subsidence caused extensive damage to buildings and services of the hostel (a $2M development) with lesser damage to nine private homes. Williams (1985) estimates remedial measures for the hostel and homes to cost approximately $450,000 and $14,000 respectively. These figures do not include the decline in capital value of an adjacent 30 section subdivision, or the loss of accommodation in the hostel.

Since the hostel subsidence two more areas of significant ground movement have occurred in the Huntly Borough over the East Mine. Settlements up to 1140mm have been recorded in these areas.

1.2 Thesis Objectives

This study was initiated as a result of recommendations made by S.C.M. (State Coal Mines) and M.W.D. (Ministry of Works and Development) in preliminary reports addressing the subsidence problem (Depledge 1983a; McInally, 1983a and Williams, 1983).

Thesis objectives are:

1) to determine the cause(s) and mechanism(s) of subsidence above the south headings of the Huntly East Mine.

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1. See Appendix One for definitions of settlement and subsidence in this thesis.

2) to develop an engineering geological model for the subsidence.

3) to provide a numerical analysis of the model where calculated and observed settlements are compared.

4) to define implications of the study with respect to existing and future coal mining in the area.

Although this study focuses on the first case of significant subsidence above the Huntly East Mine, observations from more recent occurrences are incorporated for the overall analysis.

It is beyond the scope of this study to propose or detail preventative or remedial measures for the subsidence problem.

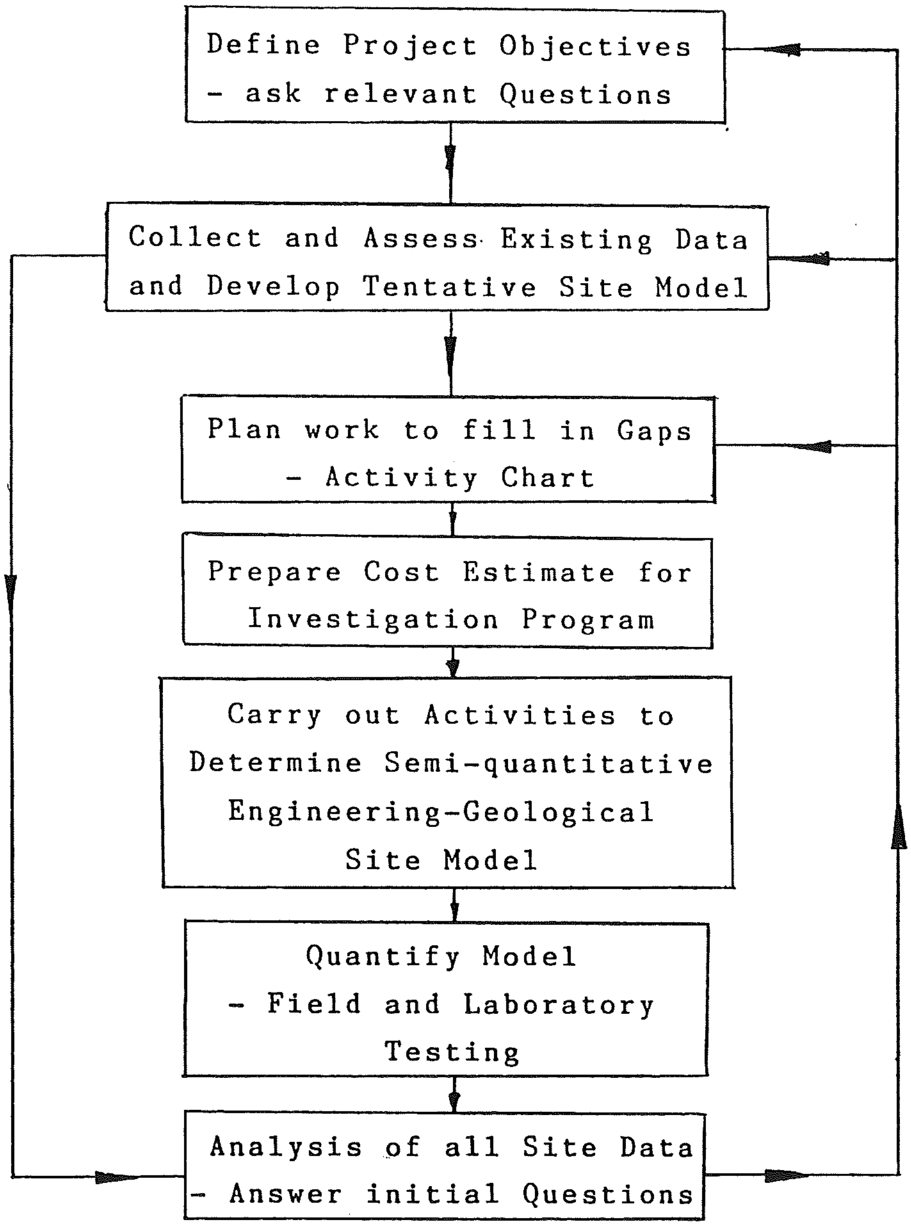
1.3 Investigation Methodology

The approach adopted for the subsidence investigation is illustrated in Figure 1.1. This objective-oriented procedure, originally developed by an International Society of Rock Mechanics Commission (I.S.R.M., 1975), has been widely applied to site investigations (e.g. Stapledon, 1979; Bell and Pettinga, 1983) and was considered to be a suitable framework for this study.

1.4 Local Setting

1.4.1 Site Location

The Huntly Borough is situated on the banks of the Waikato river 80km south of Auckland (Figure 1.2). The N.Z.E.D. Hostel is part of the Kimihia subdivision located in Huntly East. The N.Z.E.D. Hostel subsidence is the most southerly of the three subsidence areas with settlements greater than 100mm above the Huntly East Mine.



Arrows indicate iterative feedback process to solve additional problems found during main investigation program.

Figure 1.1: Objective orientated approach to site investigations (based on I.S.R.M., 1975; Bell and Pettinga, 1983). This conceptual framework has been adopted for the subsidence investigation.

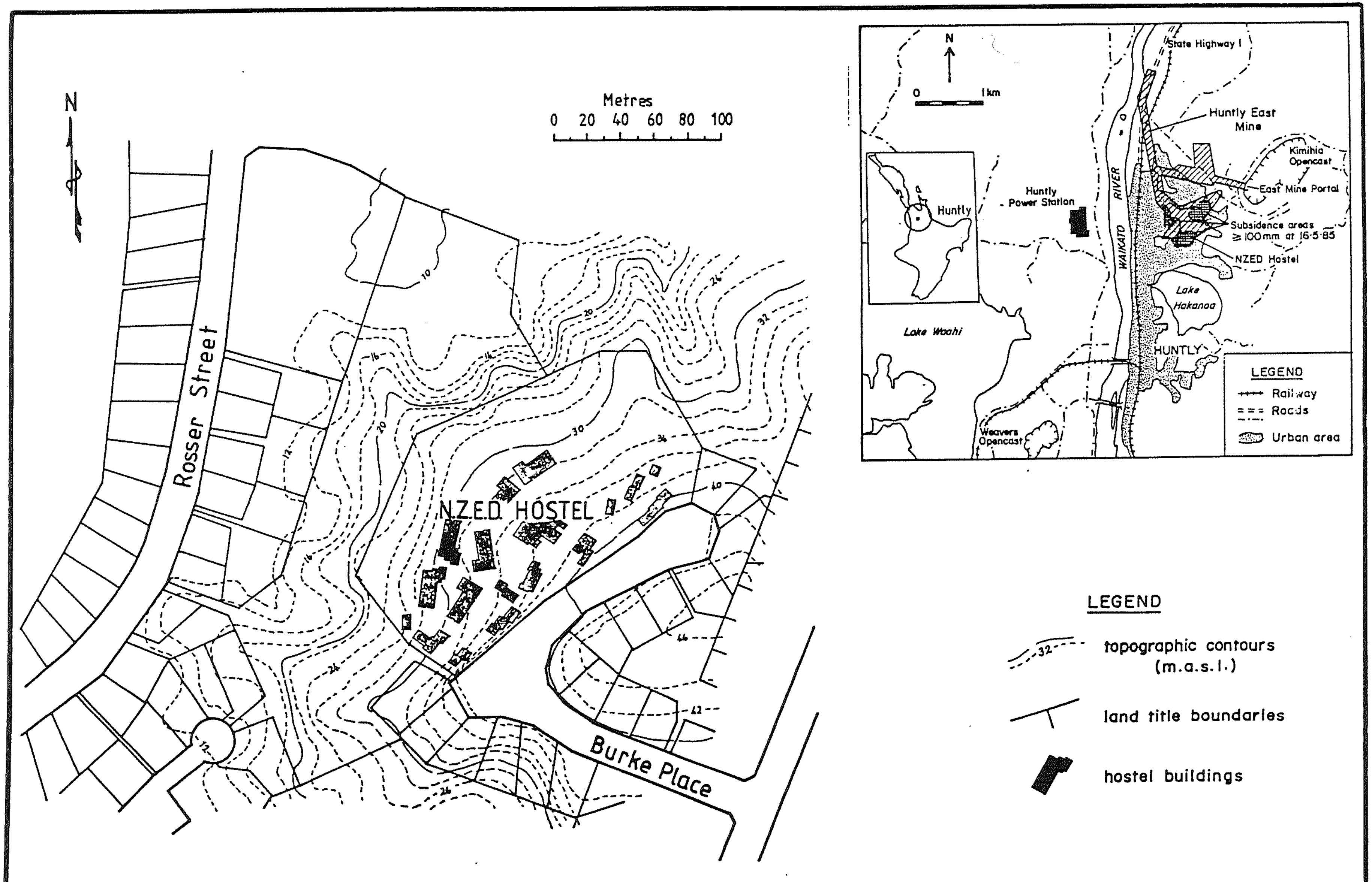


Figure 1·2: Locality map showing the extent of the Huntly East Mine workings and areas of subsidence

1.4.2 Coal Mining

The Huntly East mine was opened in 1977 and is presently the largest producing coal mine in New Zealand with an annual production of approximately 300,000 tonnes. From the worked out Kimihia Opencast, East Mine drives extend west under the Huntly township (Figure 1.3a). The area north of the drives, known as the northern headings is presently being developed for longwall mining which is due to commence in 1987.

The south headings, which extend under the Huntly township, are currently mined using the room and pillar method. South headings development involves the excavation of main access and service drives to the southeast with a later retreat phase, extracting the coal in a series of panels. Original design dimensions of room and pillar workings were drives 5m wide and 3.5 or 6m high, depending on floor coal extraction. Pillars 15m x 15m were left for roof support. Since the hostel subsidence, the pillar size has been increased to 15m x 20m, with an offset to reduce roof spanning distances. A plan of the south headings, showing the numbering of panels and different room and pillar geometries is shown in Figure 1.3b.

The panel 1 workings under the N.Z.E.D.. Hostel are 100 to 110 metres below the surface. Mining took place in this area between January and August 1982.

1.4.3 Urban Development

Stage 3 of the Kimihia subdivision, which includes the hostel was developed in the late 1970s by Murray North Partners Ltd. and the M.W.D. (Ministry of Works and Development). Development of the originally low lying poorly drained land involved (see Figure 1.4):

1) removal of peat and other unsuitable foundation materials to reserve areas.

2) filling with approximately 1.0-1.5m of sand to ground water level.

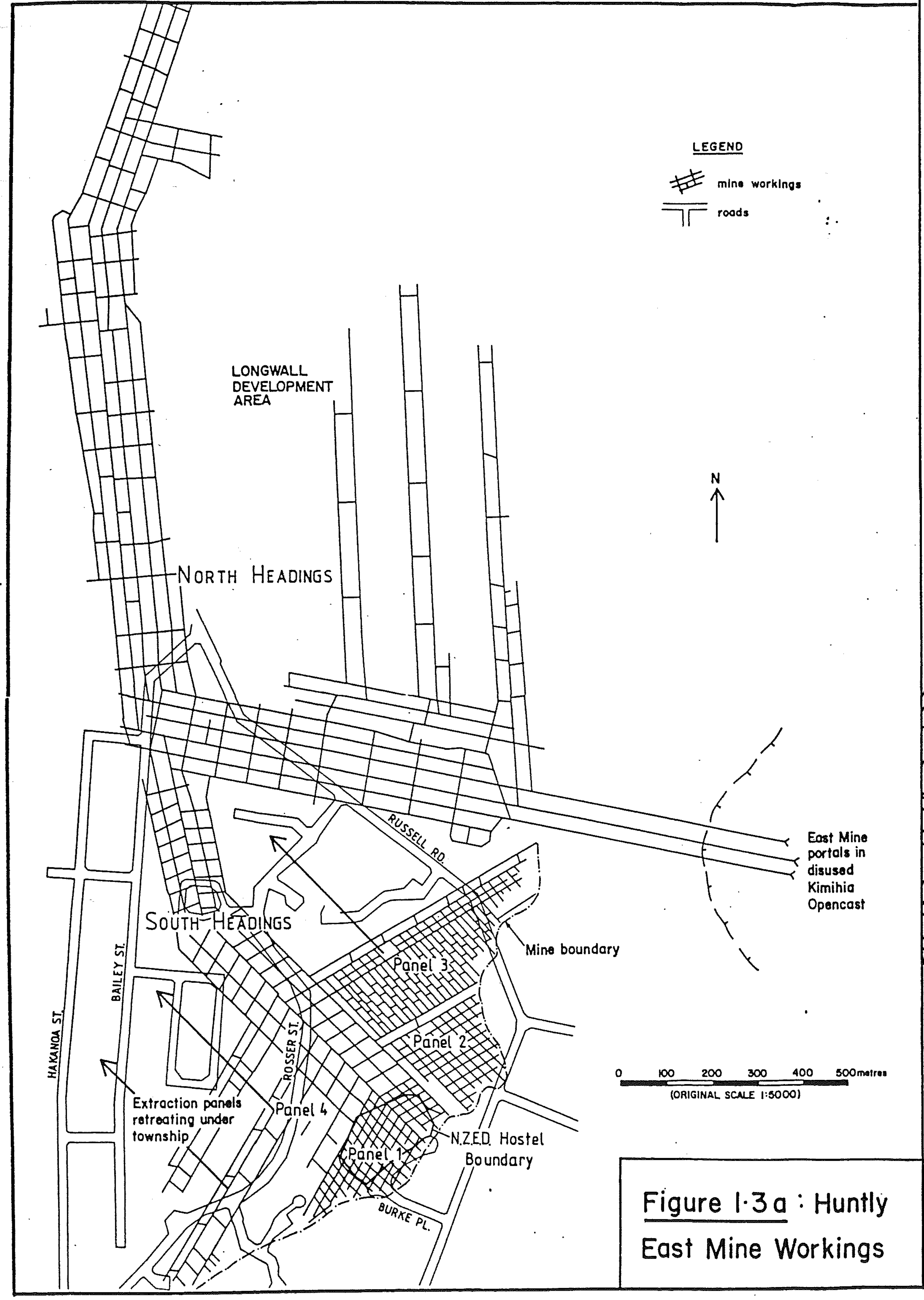


Figure 1·3a : Huntly East Mine Workings

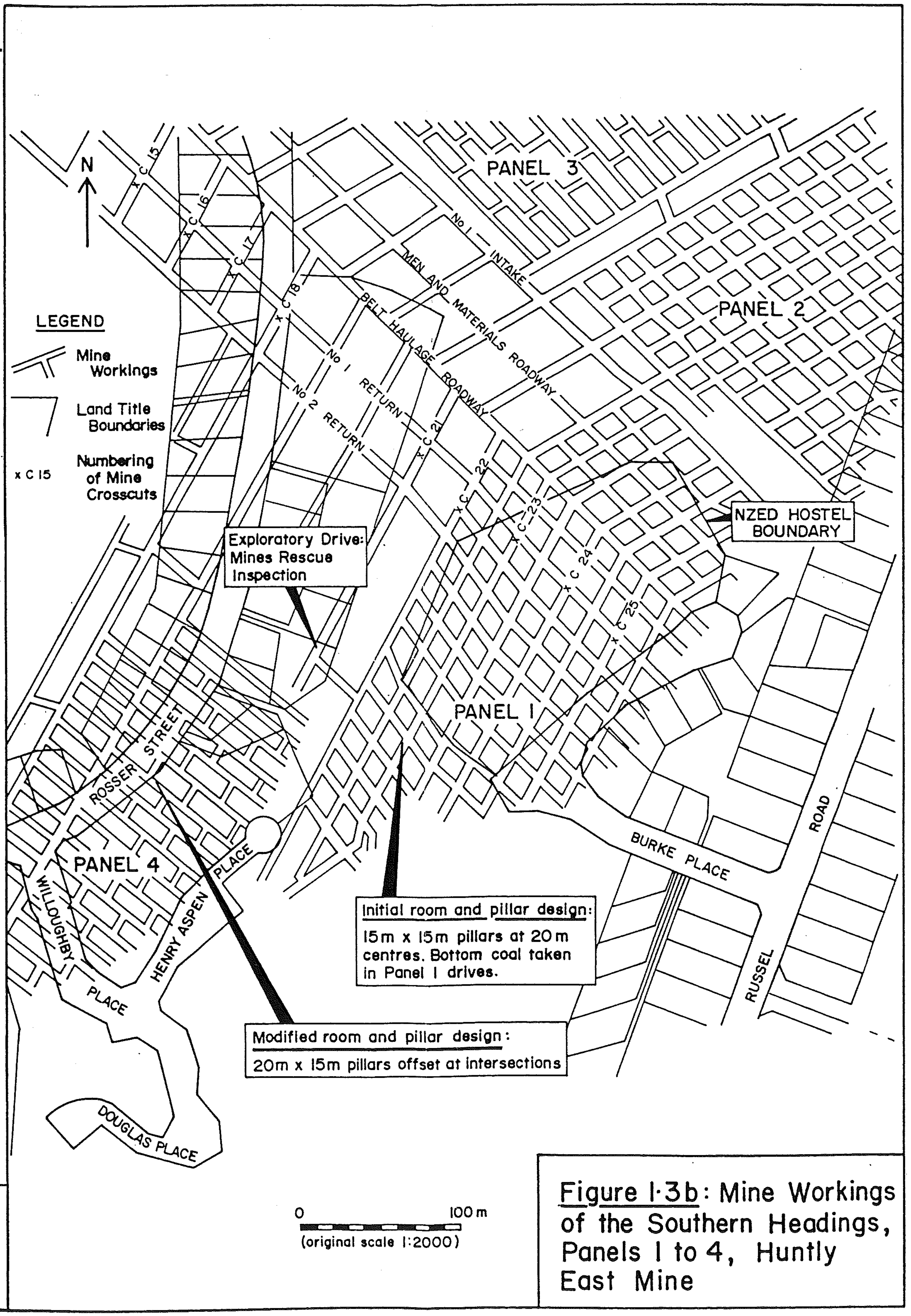


Figure 1·3b: Mine Workings of the Southern Headings, Panels 1 to 4, Huntly East Mine

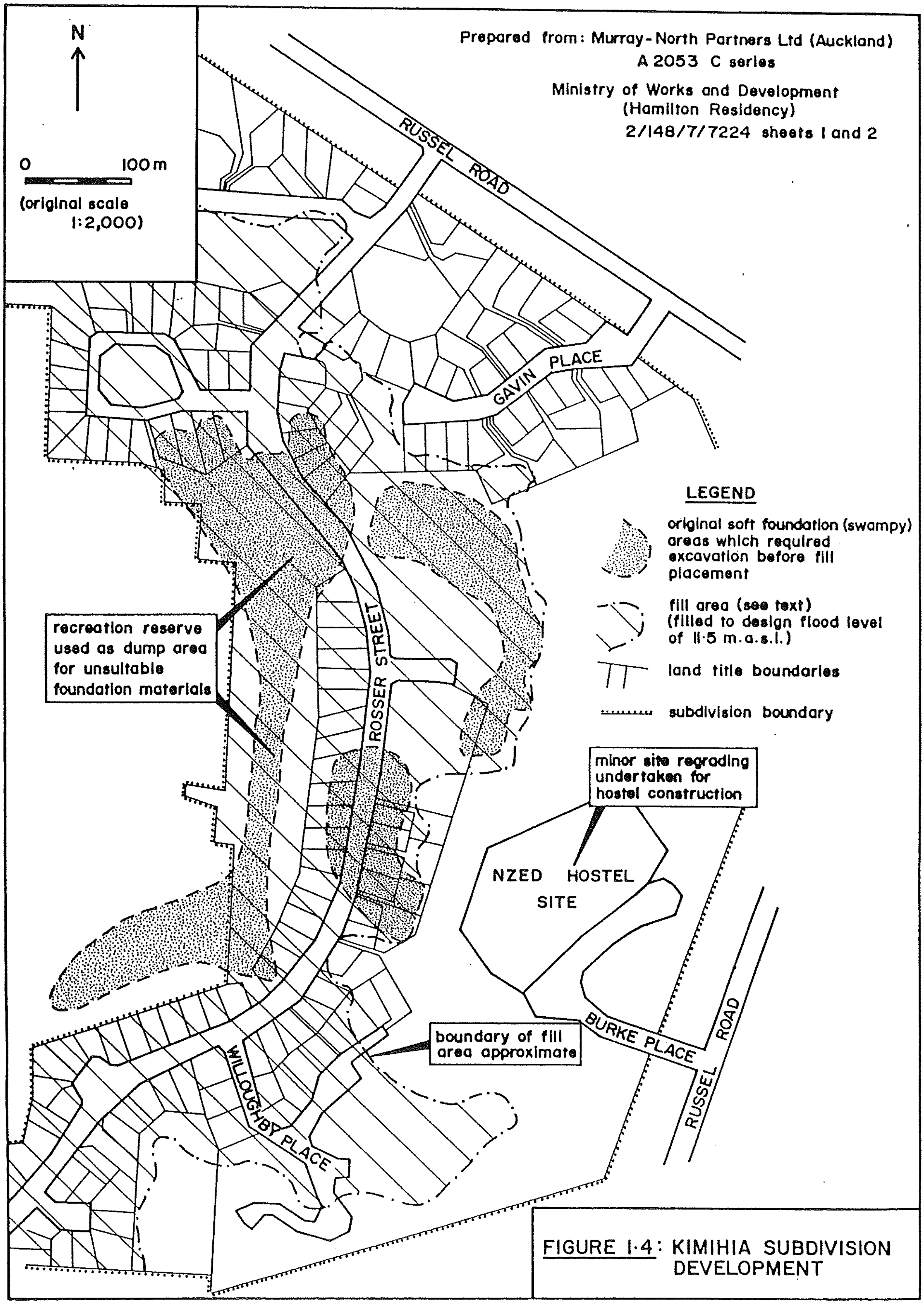


FIGURE 1·4: KIMIHIA SUBDIVISION DEVELOPMENT

3) filling with 1.0-2.0m layer of recompacted coal measures mudstone from the adjacent Kimihia Opencast to the 'design flood level' of 11.5 m.a.s.l.

4) covering of mudstone with approximately 20cm of sand to aid drainage which was in turn covered by a veneer of top soil.

5) tapping of natural springs at ground level and drainage into the stormwater system (pers. comm. J. Kendrick, 1984 - M.W.D. supervisor involved in Kimihia Block development).

Most hostel buildings and residences affected by subsidence in the area are single storey brick veneer structures (Figure 1.5). Cracking of brick veneer through differential settlement in houses in Rosser Street was reported soon after construction but before mining commenced. This is interpreted by Williams (1983) as being caused by consolidation settlement due to fill emplacement.

Foundation works at the hostel consisted of minor site regrading. Springs evident in pre-development aerial photographs (Section 3.2.1), on slopes below the hostel, have been piped into the stormwater system (pers. comm. J. Kendrick, 1984).

1.5 Regional Setting

1.5.1 Introduction

This review section is based on the 1:250,000 geological maps of Schofield (1967) and Kear (1960) plus New Zealand Geological Survey (D.S.I.R.) Bulletins of Kear and Schofield (1978) and Schofield (1972). Aspects of East Mine geology and hydrology are summarised from S.C.M. mine plans and assessments presented by B.M.C. (1984) and Todd (1982b). The primary objective of this review is to define aspects of regional geology and geomorphological development relevant to subsidence problems above the south headings.

Figure 1.5: Northeasterly view of Rosser Street housing with N.Z.E.D. Hostel on hill in background (Photograph J.R. Pettinga).

1.5.2 Regional Geology

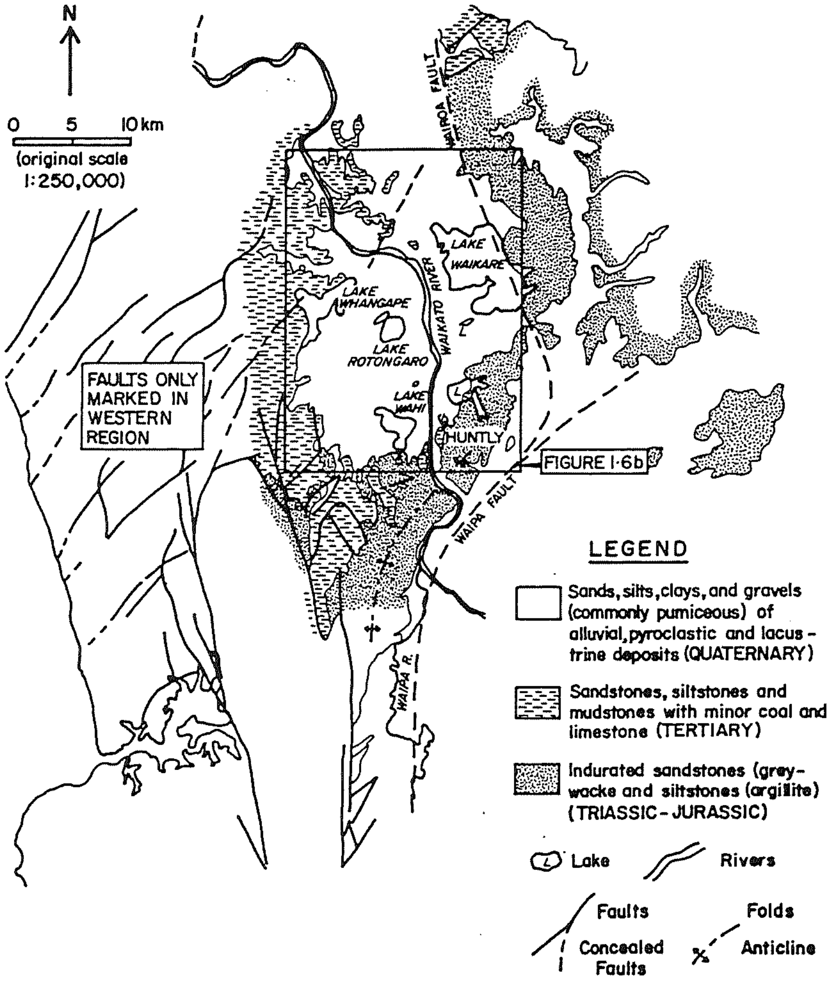
1.5.2.1 Stratigraphy

The stratigraphy of the Waikato area consists of Triassic to Jurassic basement rocks of the Hokonui System, Tertiary strata of the Te Kuiti and Waitemata Groups, plus Pliocene to Holocene unlithified deposits of the Tauranga Group (Figures 1.6 and Table 1.1).

Hokonui rocks are part of the extensive North Island Mesozoic basement. Typical lithologies are moderate to highly indurated sandstone and siltstone. The Hakarimata Formation, the basal unit of the Hokonui system in the area, forms the basement at the Huntly East Mine. Within the mine, the top of the basement is marked by a clay rich weathering zone typically 5 metres but ranging from 0.5 to 20 metres thick (pers. comm. R. Gregg, 1984 - S.C.M. geologist). The weathering zone grades into the underlying highly indurated siltstones and sandstones.

Unconformably overlying the basement, and common throughout the North Island, is the Tertiary sequence which includes basal coal measures, mudstones, sandstones and limestones. The basal Waikato Coal Measures comprise a c.60m sequence of mudstones, sub-bituminous coals and rare fine sandstones and siltstones (B.M.C. 1984). King (1978) describes the dominant lithologies as moderately indurated, dark grey to greyish brown slightly carbonaceous mudstones and brownish black carbonaceous mudstones. King notes that the fine to medium quartzose sandstones and coarse siltstones occur in isolated beds up to 3 metres thick. The presently mined Kupakupa seam is typically 7 to 8 metres thick with the overlaying Renown seam 1 to 5 metres thick. Descriptions of lithologies from the remainder of the Tertiary sequence are presented in Table 1.1.

Common throughout the Waikato, Auckland and Bay of Plenty regions are the unlithified, Pliocene to Holocene, predominantly pumiceous deposits of the Tauranga Group. Within the Huntly region the Tauranga Group unconformably overlies the Tertiary strata, and consists of a sequence of fluvial, lacustrine and pyroclastic deposits (Kear and



Source: Schofield (1967) and Kear (1960)

FIGURE 1·6a : GEOLOGICAL MAP OF THE NORTHERN WAIKATO.

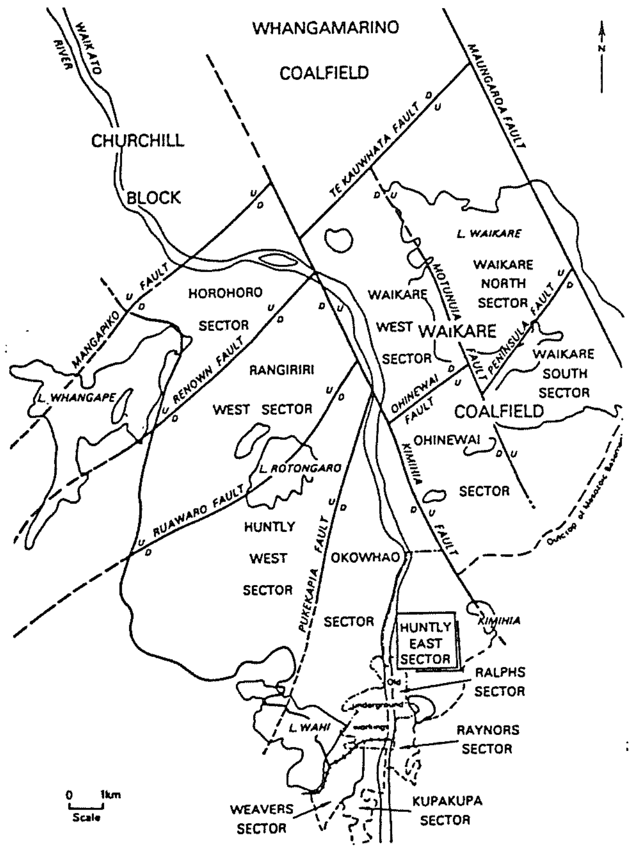


FIGURE 1·6b : FAULTS IN THE HUNTLY AND WAIKATO COALFIELDS (courtesy of N.Z. Geological Survey - from Gray and Daly, 1981)

Table 1.1: Stratigraphy of the Huntly East Mine Area.

		STRATIGRAPHY	AGE	APPROXIMATE THICKNESS	MATERIAL DESCRIPTION
	TAURANGA GROUP	Taupo Pumice Alluvium	Holocene	0 - 30m	- loose, creamy white, highly pumiceous silt, sand and sandy conglomerates commonly containing charcoal and bedded
	TAURANGA GROUP	Hinuera Formation	Pleistocene	0 - 100m	- yellow brown silts, sands gravels and peat, highly pumiceous and commonly cross-stratified
	TAURANGA GROUP	Hamilton Ash	Pleistocene	0 - 3m	- multilayered sequence of halloysitic yellow brown pinkish grey, firm, blocky, ashes (sandy silty clays) with prominent white veins
	TAURANGA GROUP	Kauroa Ash	Pleistocene	0 - 4m	- multilayered sequence of halloysitic, brown, yellow and pink commonly mottled ashes (clay rich) with manganese nodules
	TAURANGA GROUP	Karapiro Formation	Pleistocene	± 30m	- brown and yellow brown, pumice-rock fragment (volcanic and greywacke) -quartzfeldspar sands and coarse gravelly sands, with some interbedded white/ brown silty clays and peats
	TAURANGA GROUP	Waeranga Gravels	Pleistocene	-	- highly weathered greywacke gravels
	TAURANGA GROUP	Puketoka Formation[1]	Pleistocene	-	- pure pumiceous, sands and silts, breccias and distal deposits of ignimbrite flows interbedded with peats
	TAURANGA GROUP	Whangamarino Formation	Pliocene	± 30m	- green and brown fine silts and clays, with inter-bedded rare peat and common to abundant green, quartz-ofeldspathic rock fragment-pumice sands and coarse gravelly sands
					UNCONFORMITY
	TE-KUITI GROUP	Whaingaroa Siltstone	Oligocene	+ 80m	- massive grey, moderately calcareous siltstone
	TE-KUITI GROUP	Glen Massey Formation	Oligocene	± 15m	- glauconitic fine to medium sandstone (Glen Massey Sandstone) with lenses of calcareous siltstone (Elgood Limestone) at base
	TE-KUITI GROUP	Mangakotuku Siltstone	Oligocene	± 80m	- non calcareous, massive siltstone-silty claystone with minor calcareous beds
	TE-KUITI GROUP	Pukemiro Sandstone	Oligocene	± 5m	- glauconitic sandstone
	TE-KUITI GROUP	Glen Afton Claystone	Oligocene	± 30m	- non-calcareous silty claystone
	TE-KUITI GROUP	Waikato Coal Measures	Eocene	± 60m	- kaolinitic, light brown mudstones to highly carbonaceous fissile mudstones with coal seams towards the base. Siderite concretions occur throughout
					REGIONAL UNCONFORMITY
HOKONUI SYSTEM	NEWCASTLE GROUP	Hakarimata Formation	Upper Triassic	-	- highly indurated siltstone and sandstone

Prepared from: Kear and Schofield, (1978); B.M.C., (1984); Todd, (1982) and Ward, (1967).

[1] The Puketoka Formation is absent from the East Mine Area (Todd, 1982).

Schofield, 1978; Todd, 1982a).

Todd (1982b), as part of a groundwater investigation recognised the Whangamarino Formation, Karapiro Formation, Waeranga Gravels, Hinuera Formation and Taupo Pumice Alluvium within the Tauranga Group above the East Mine. The Puketoka Formation is notably absent. Volcanic tephras mantling low hills surrounding Huntly (pers. obs.) are considered to be part of the Kauroa and Hamilton Ash deposits described within the Lower Waikato Basin by Ward (1967).

1.5.2.2 Structure

Normal faults within the basement and Tertiary sequences in the Huntly area are numerous and define coal field sector boundaries (Figure 1.6b).

The East Mine is bounded to the east and west by 2 normal subparallel N-S trending faults c.1km apart (Figure 1.7). Within the workings a second set of NE (050^{o}-070^{o}) striking normal faults with variable throws of less than 5 metres can be found. S.C.M. studies (B.M.C.,1984) show that regional face cleat orientation ranges from 040^{o} to 070^{o} with butt cleat from 120^{o} to 150^{o}. Cleat intensity is highest adjacent to the NE trending faults and crush zones.

Tertiary strata thickness is highly variable (Figure 1.7) due to the gentle basement relief, the 5^{o} to 15^{o} NW sequence dip and moderate relief on the Te Kuiti-Tauranga Group erosional contact. For the upper contact over the East Mine, cross-sections constructed from S.C.M. mine plans (based on a 200 metre borehole spacing) show c. 30 metres of relief over a distance of c.300 metres (Section B-B', Figure 1.7). In the Weavers Opencast area where the borehole spacing is c.40m. the Te Kuiti-Tauranga Group contact shows 20 to 40 metres of relief over a distance of 50 to 100 metres (Henderson, 1983).

S.C.M. cross-sections (Todd, 1982c) show that the Tauranga Group deposits are commonly channelised with lateral and vertical lithological variations over short distances.

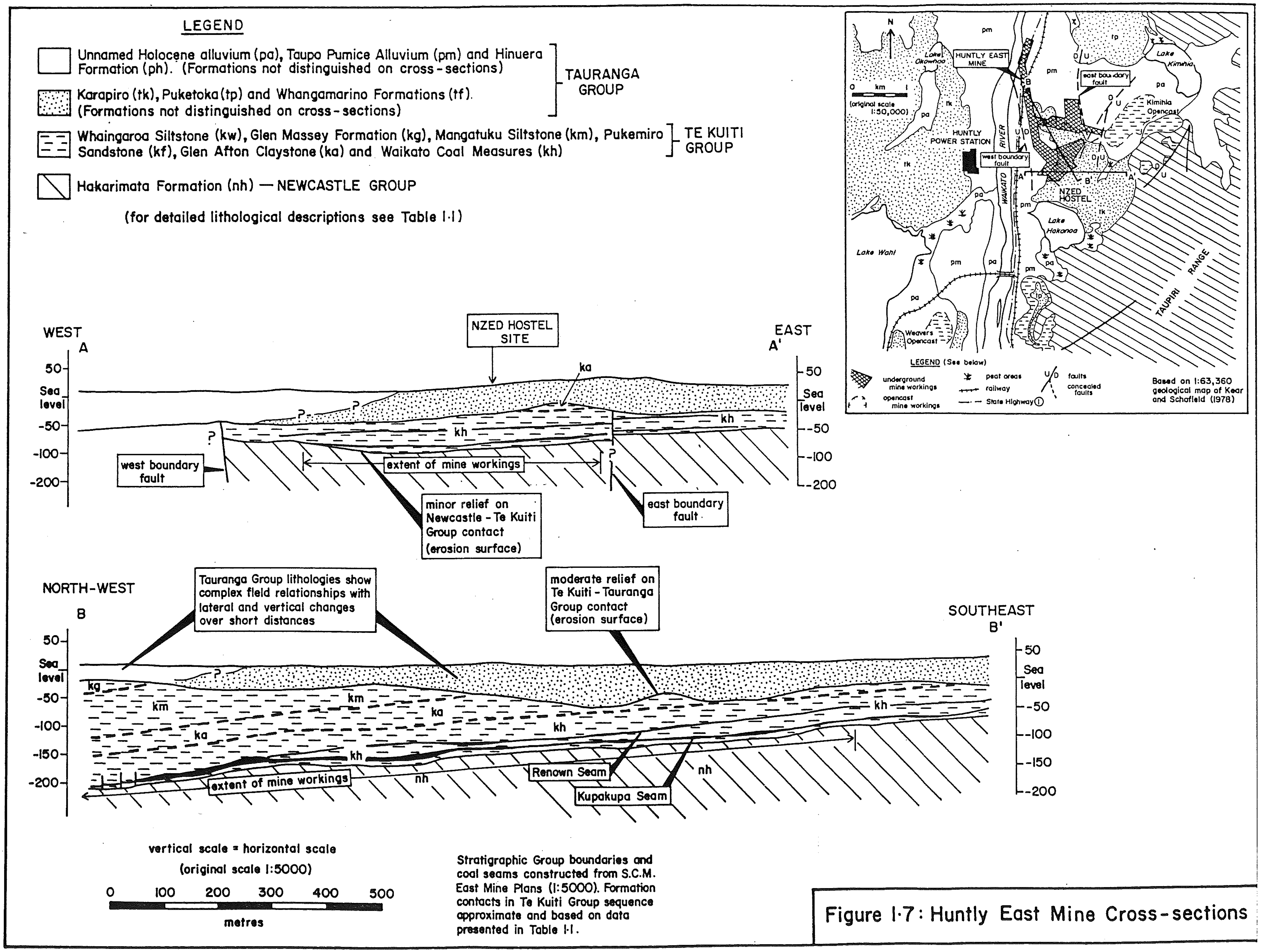


Figure 1·7: Huntly East Mine Cross-sections

Fig 1·7

1.5.3 Regional Geomorphology

The present gross landscape features (Figure 1.8) are controlled by block faulting of Tertiary and basement strata with subsequent partial burial by the Tauranga Group sequence (Selby, 1982).

The most prominent landform features are the steep and rugged Hakarimata and Taupiri Ranges with up to 300 metres of relief. These ranges, comprised of basement rocks trend SW-NE and immediately south of Huntly are cut through by the Waikato River in the Taupiri Gorge.

By contrast, the Tertiary strata, form a moderately undulating landscape with broad stream valleys. Coarser and more calcareous units form bluffs up to 30 metres high. Hill sides of Tertiary mudstones are commonly hummocky due to slope instability.

The Huntly township is situated on the edge of the extensive Lower Waikato Lowland. The present geomorphic features of the lowland are the result of cyclic phases of aggradation and degradation (Kear and Schofield, 1978). The low rolling hills which rise above the lowland represent the oldest known phase of major aggradation with the deposition of the Whangamarino, Puketoka and Karapiro Formations plus the Waeranga Gravels (Pliocene to Pleistocene). This sequence was subsequently eroded before the deposition of the Kauroa and Hamilton Ash deposits (Selby, 1982) and Hinuera Formation (Pleistocene). The Waikato River and its tributaries have subsequently eroded into this succession. The erosion was temporarily interrupted when the Taupo Pumice Alluvium from the 186 A.D. Taupo Eruption (Wilson et al., 1980) filled the Waikato Valley forming the latest aggradation surface. Most of the present flat swampy topography surrounding Huntly represents the top of the Taupo Pumice Alluvium aggradation surface. Geomorphic development of the Lower Waikato Lowland is schematically illustrated by Figure 1.9.

1.5.4 Regional Hydrology

Climate of the area is mild with rainfall evenly

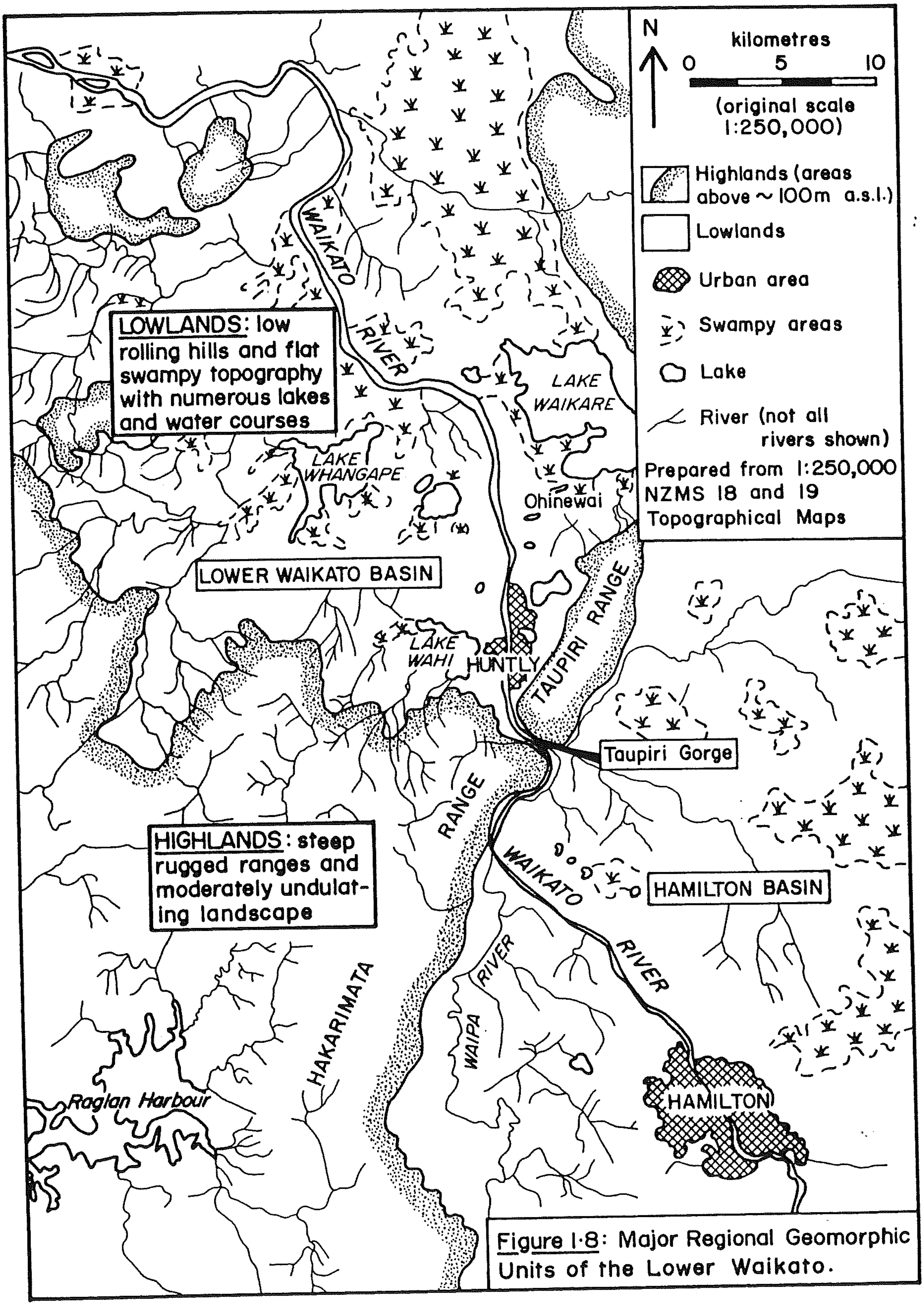


Figure 1·8: Major Regional Geomorphic Units of the Lower Waikato.

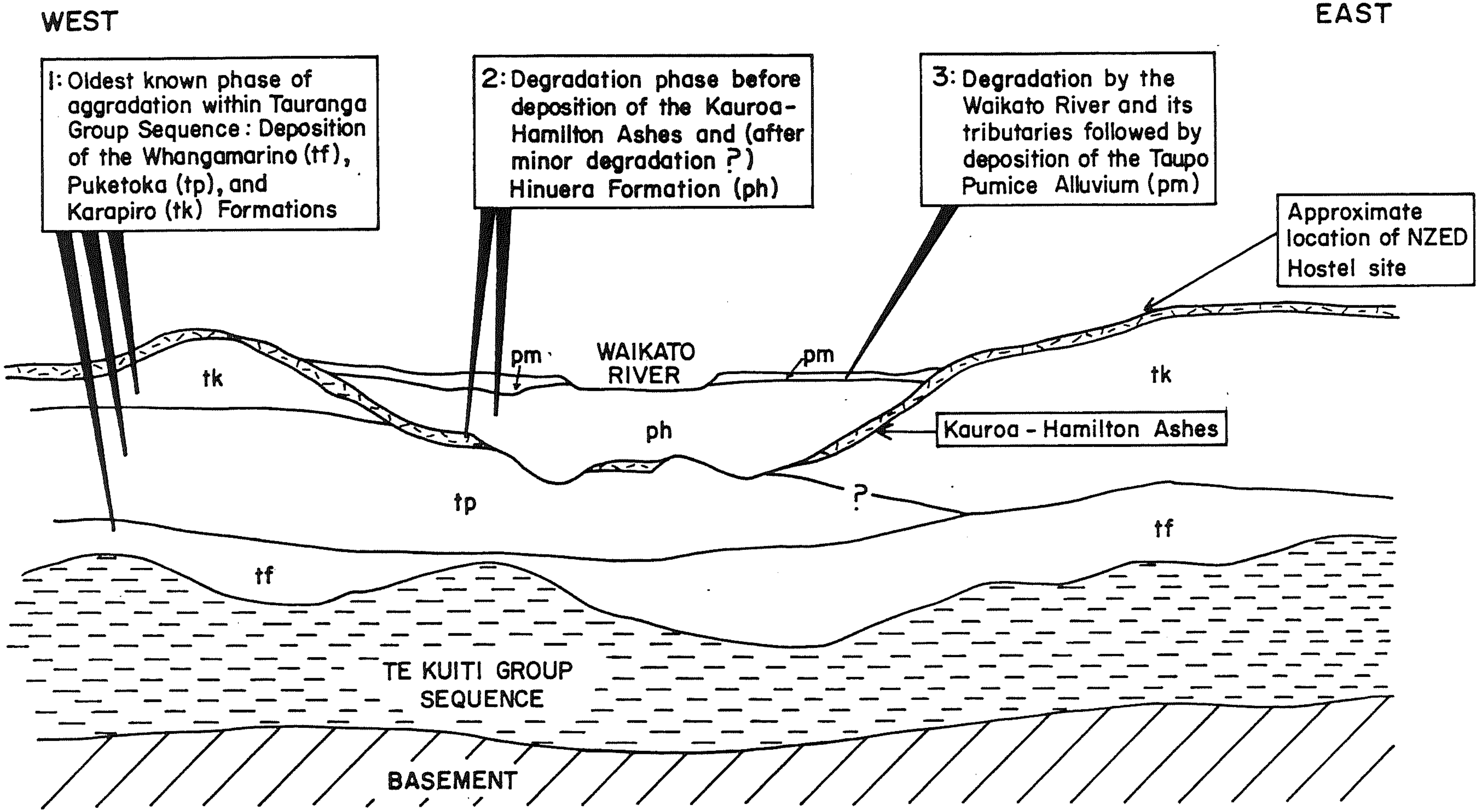


Diagram not to scale. Stratigraphic contacts approximate only. Construction is based on the regional study by Kear and Schofield (1978) and East Mine Tauranga Group interpretation by Todd (1982 b)

Figure 1·9: Schematic geological cross-section showing the geomorphic development of the Huntly area as determined by cycles of aggradation and degradation within the Tauranga Group sequence.

distributed throughout the year and only slightly increasing in winter months. Data from the Huntly meteorological station gives a 1273mm mean annual rainfall with a range of 913-1592mm between 1940-1981. All surface drainage is either to the Waikato River or the numerous lakes on the Lower Waikato Lowland.

The Tauranga Group sequence contains extensive high yielding aquifer[1] systems and over the East Mine at least two of these systems are present (Todd, 1982; B.M.C., 1984). The upper system is regionally extensive, generally 10 to 30 metres thick and comprises the Taupo Pumice Alluvium, Hinuera Formation, Waeranga Gravels, Karapiro Formation and part of the Whangamarino Formation. This system is unconfined and appears to be laterally continuous with the Waikato River. The lower aquifer system is approximately 5 to 10 metres thick and limited in extent to the channels on the Te Kuiti-Tauranga Group contact. The aquifer systems are separated by 10-25m of silts and clays which form a semi-confining layer or aquitard. The semi-confined lower aquifer system and the aquitard are both part of the Whangamarino Formation.

Te Kuiti and Newcastle Group deposits can be considered an aquiclude apart from areas of fractured ground or coal seams where permeability may be locally higher. A summary of the major hydrogeologic units is presented on Table 1.2.

1.5.5 Synthesis: Implications of Regional Factors to Hostel Site

Regional factors considered important to the site are that:

1) the subsurface geology of the site consists of Tauranga, Te Kuiti and Newcastle Group materials, each distinct in terms of lithology and structure.

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1. See Appendix One for definitions of hydrologic terms.

Table 1.2: Hydrostratigraphic Units - Huntly East Mine Area (after B.M.C., 1984).

	STRATIGRAPHY AND MATERIAL DESCRIPTION	THICKNESS (m)	WATER YIELDING CHARACTERISTICS	POROSITY (n)	HYDRAULIC CONDUCTIVITY (PERMEABILITY: k in m/s)
TAURANGA GROUP	UPPER AQUIFER Coarse pumice sand, gravel with minor silt, mud and peat layers. (Hinuera Formation, Taupo Pumice Alluvium and Karapiro Formation)	10 - 30	High yielding	35 - 67	2×10^{-5} to 4×10^{-4}
TAURANGA GROUP	AQUITARD Silts, silty clay, muds silty very fine sands; minor coarse sand and gravel layers (part of Karapiro and Whangamarino Formations)	10 - 25	Low yielding except for thin sand or gravel horizons	40 - 60	10^{-8} to 10^{-4}
TAURANGA GROUP	LOWER AQUIFER Fine to coarse silty sands alternating with medium to coarse greywacke gravels, minor clays and silts (part of Whangamarino Formation)	5 - 10	Suspected high yielding	35 - 60	1.2×10^{-5} to 3.8×10^{-5}
TE KUITI GROUP	Mangakotuku Siltstone[1] Pukemiro Sandstone Glen Afton Claystone Waikato Coal Measures	-	Virtually dry except near fractured ground or coal seams (AQUICLUDE)	less than 10	10^{-10} to 10^{-8} with 10^{-7} + 10^{-5} for some coal seams and possibly the Pukemiro Sandstone
	Greywacke basement	-	-	-	-

[1] For material descriptions and approximate thicknesses of Te Kuiti Group strata see Table 1.1

2) the geometric constraints to the thickness of Tertiary overburden above mine workings are the 5-15^{o} NW dip of the Te Kuiti Group sequence and the moderate relief on the Te Kuiti-Tauranga Group erosional contact (overburden stresses are also controlled by these two factors combined with surface relief determining Tauranga Group overburden thickness).

3) the Tauranga Group lithologies show complex field relationships with lateral and vertical variations over short distances.

4) high yielding aquifers are present within the Tauranga Group overburden at the site.

5) the only active process considered to be present at the N.Z.E.D. Hostel (apart from subsidence) during early 1983 is ground water movement.

CHAPTER II

PREVIOUS INVESTIGATIONS AND DEVELOPMENT OF SITE MODEL

2.1 Introduction

This chapter reviews and describes the development of the hostel subsidence and associated investigations. The chapter is based on reports, survey monitoring data, and personal observations from S.C.M., L.S. (Department of Lands and Survey) and M.W.D. These previous investigations are combined with the regional studies of Section 1.5 to develop a tentative engineering geological site model.

2.2 Survey Monitoring

Since 1978 a survey network has been established by L.S. over the East Mine to monitor mining related movement. Figure 2.1 shows the network over the south headings in relation to the mine geometry and the urban area. Average distance between marks is 100m. Bradley (1982), in his review of the monitoring, specifies the horizontal and vertical accuracies as ± 10mm and ± 3mm respectively. From observations of marks not affected by mining activity, Bradley reports that seasonal vertical movement from natural causes is generally less than 5mm.

Monitoring to July 1985 has identified 3 areas of subsidence greater than 100mm. Area location, subsidence timing and maximum measured settlements are shown in Figure 2.1. Subsidence above the south headings although irregular, is trough shaped and generally follows mine geometry. Limit angles or angle of influence (Figure 2.2) range between 38^{o} and 71^{o} for the 5mm subsidence contour.

The survey marks most affected by the hostel subsidence are E53 and E61. Settlement-time plots for these marks are presented in Figure 2.3. Features to note are that:

1) the subsidence is characterised by two phases of rapid movement with a maximum calculated settlement rate of 36mm/day.

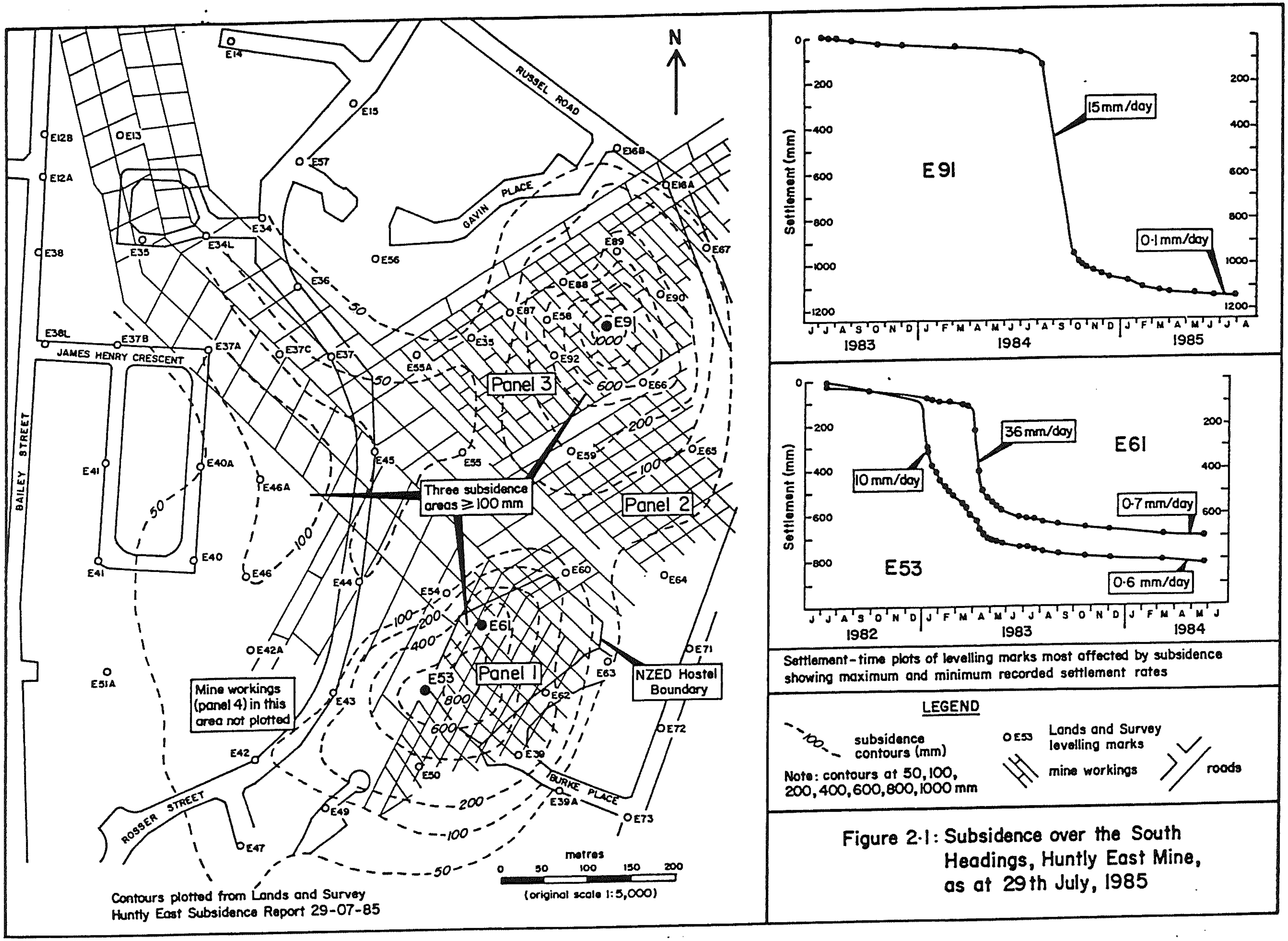


Figure 2·1: Subsidence over the South Headings, Huntly East Mine, as at 29th July, 1985

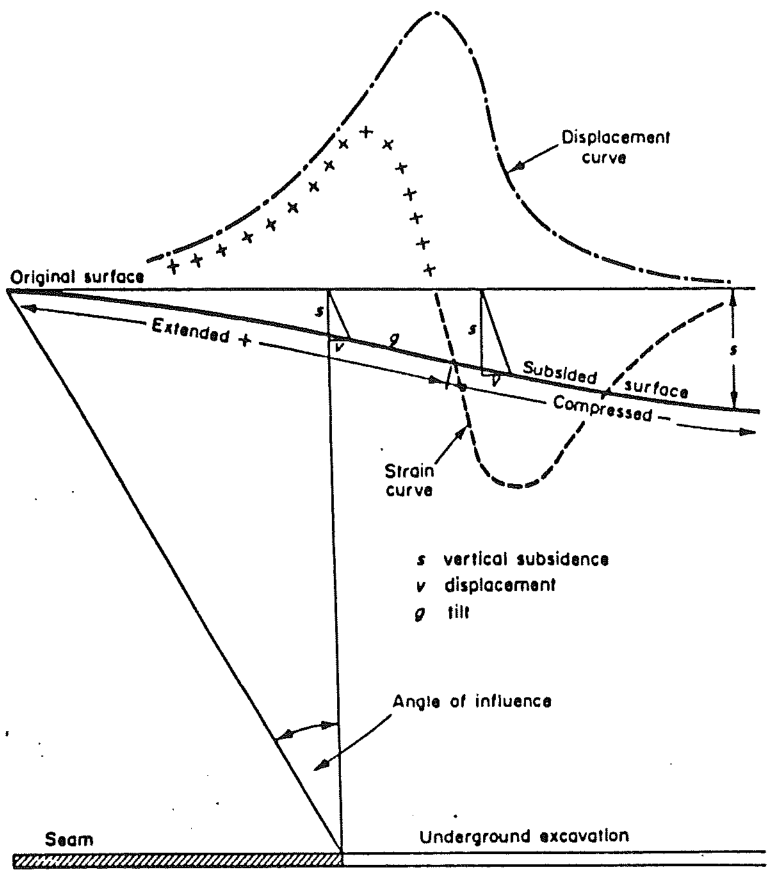


Figure 2.2: Sectional view of an idealised subsidence trough showing the relationships between the various geometric parameters (Bell, 1975).

2) settlement rates gradually reduce after the rapid phases (additional data shows that the settlement rates became constant approximately 12 months after the rapid phases with constant rates evaluated at 0.7 and 0.6mm/day for E61 and E53 respectively).

3) approximately 85mm of settlement occurred for both marks before the first rapid phase commenced.

Incorporating settlement data from other survey marks subsidence profiles can be constructed across the hostel site (Figure 2.4). Profiles show the development of the trough with the easterly migration of subsidence associated with phase II rapid movement.

M.W.D. established a levelling network in the hostel grounds on the 12th January, 1983. Spacing of M.W.D. marks is approximately 20 metres, the marks being installed on concrete paths, kerbing and tarseal. Estimates of total settlement at these locations can be made using original building levels and site grading plans. Where possible this data is incorporated with L.S. data to construct subsidence contour plans (Figures 2.5 and 2.6).

Subsidence contours at the 14th March 1983, show the trough to be nearly circular with an approximate diameter of 300m. Contours plotted for the 2nd August 1983 show similar features to the subsidence profiles (Figure 2.4) with the locus intensifying and a general northeasterly propogation of subsidence.

Vectors showing horizontal movement of L.S. survey marks for both phases of rapid movement are also shown on Figure 2.5 and 2.6. A circular 'dish' shaped subsidence produces horizontal movement vectors which intersect at the point of maximum subsidence. Due to the irregular nature of the subsidence trough hostel vectors for both phases of subsidence have areas of intersection. Vector data suggests that the area of maximum subsidence has migrated approximately 60 metres northwest. The apparent easterly migration of subsidence from levelling data is probably secondary to this northwesterly trend. Subsidence contours failed to reflect the northwesterly migration due to the

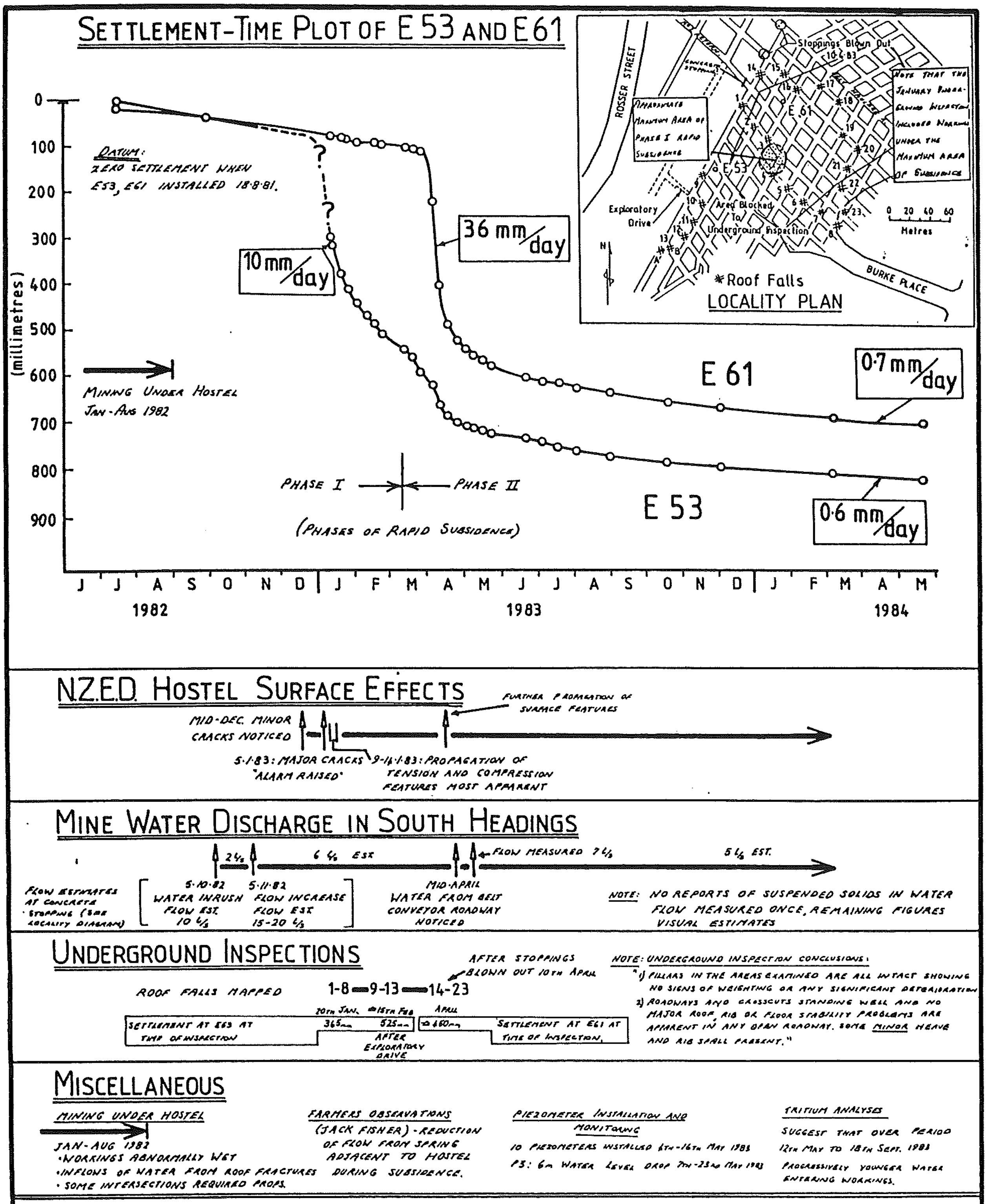


FIGURE 2.3: SUBSIDENCE AT E53 AND E61 WITH RELATED EVENTS

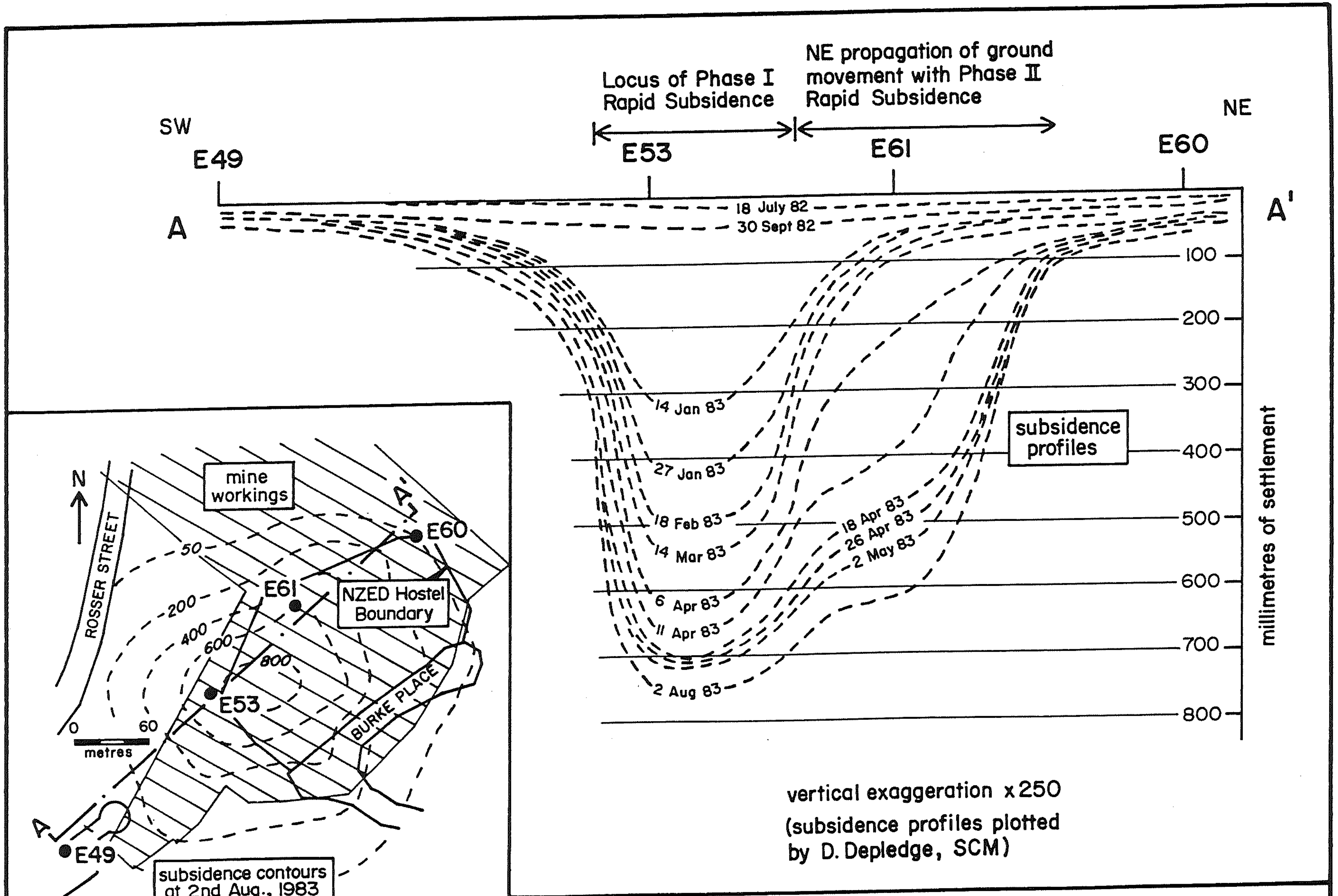


Figure 2·4: Subsidence profiles across hostel site

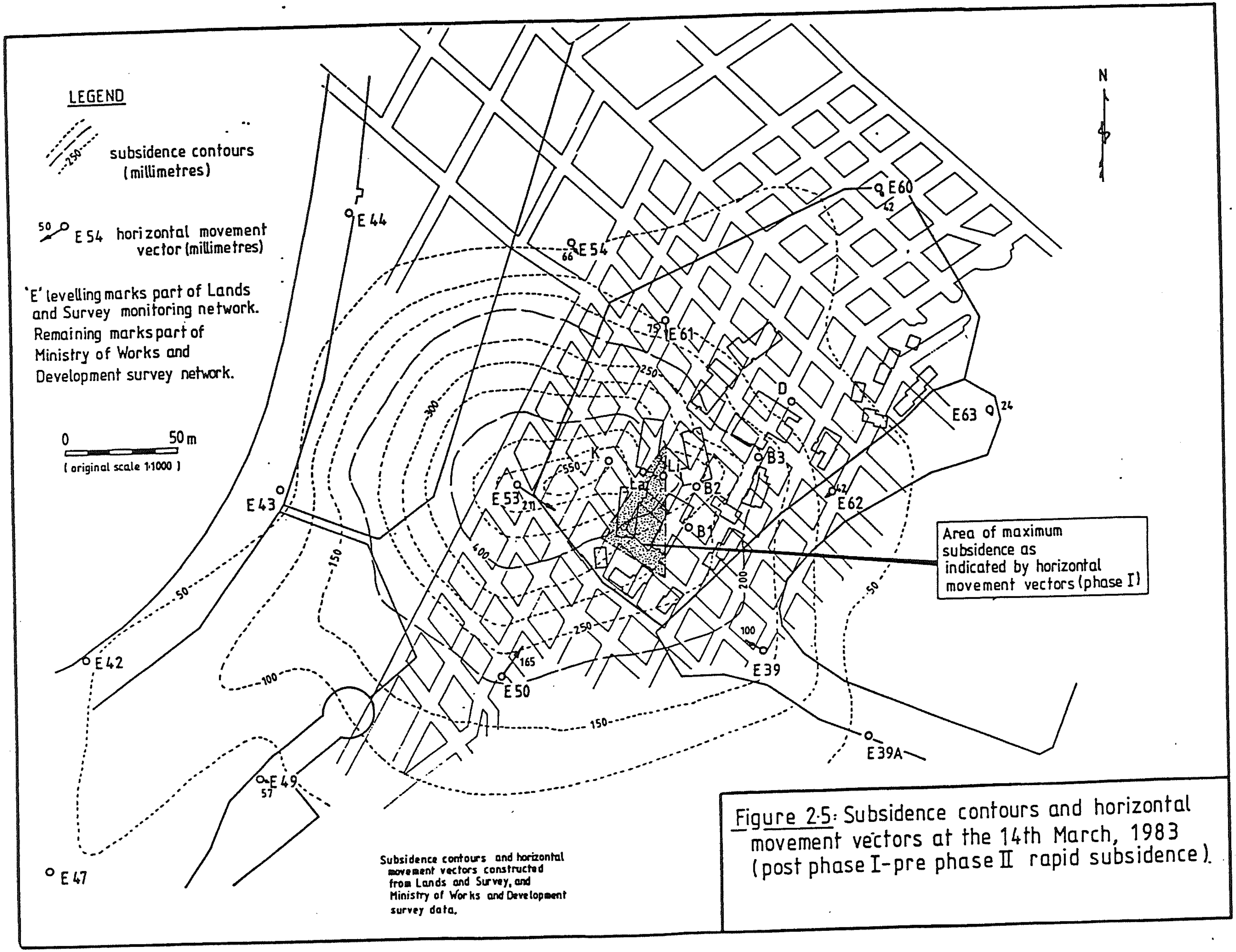


Figure 2.5: Subsidence contours and horizontal movement vectors at the 14th March, 1983 (post phase I-pre phase II rapid subsidence).

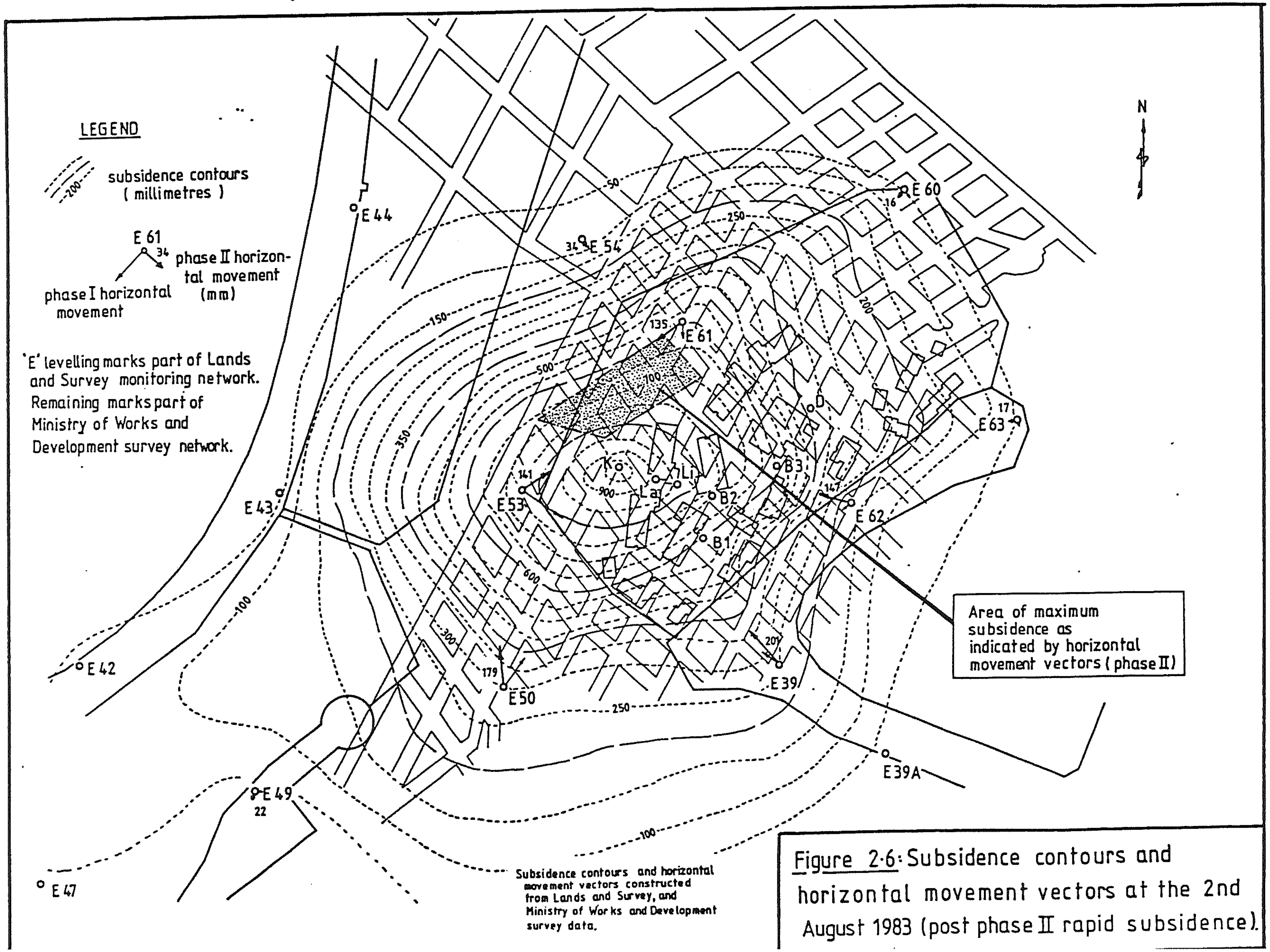


Figure 2·6: Subsidence contours and horizontal movement vectors at the 2nd August 1983 (post phase II rapid subsidence).

lack of levelling data in that area.

Maximum lateral movement detected during the hostel subsidence for monitoring to May 1984 is 296mm at E53. Maximum compression is between E39 and E53 with a shortening of 560mm in 134.5m (compressive strain is 4mm/m) and maximum tension between E39 and E39A where 60.5m is lengthened by 293mm (tensile strain is 5mm/m).

2.3 State Coal Mine Reports and Investigations

2.3.1 Mining conditions under hostel

Panel 1 below the hostel was the first area of the south headings to have pillars split and floor coal extracted. The southern and southeastern margins of the panel represent mine boundaries, in this case the result of the coal seam becoming too thin for extraction. Williams (1983) notes that the workings are in 'poor ground' with some intersections requiring propping and that the area was wet during mining with large inflows of water from roof fractures. Offord (1983), in his fortnightly mine manager's report described mining conditions as wet causing frequent bogging down of shuttle cars.

2.3.2 Mine water discharge

On the 5th October, 1982 (prephase I rapid subsidence, see Figure 2.3) a large inrush of water from panel 1 was reported (Offord, 1983) at a partially constructed concrete stopping at the end of No. 2 return (see Figure 2.3 for location). The water was reported to have a sulphury odour with an estimated flow of 10 l/s subsequently reducing to 2 l/s (Figure 2.3). At the same location on the 5th November, 1982 flow increased to an estimated 15-20 l/s subsequently reducing to 6 l/s (Williams, 1983). During mid-April 1983 discharge from panel I was noticed at another locality in the belt haulage roadway (McInally, 1983b). All reports of panel I discharge state that the water was clear and contained no suspended solids. It is important to note that the only measurement of flow from panel I is 7 l/s, recorded on the 6th May, 1983 (Depledge, 1983c). All previously stated flow rates are approximate only and based on visual observation.

S.C.M., investigating possible dewatering consolidation, carried out tests to determine the hydraulic continuity between mine discharge and overlying Tauranga Group aquifers. Water tracing procedures using fluorescein dye and salt combined with chemical and tritium analyses on mine, aquifer and surface waters were completed.

Fluorescein dye, mixed with drilling mud was pumped into sandy gravels at the bottom of M.W.D. borehole 6599 (Section 2.4) on the 20th January, 1983. Final depth of BH 6599 is 52m, approximately 17m above the Te Kuiti-Tauranga Group contact. No tracer dye in the south headings water has been recorded (Depledge 1983a). Salt (NaCl) was placed in piezometers established by S.C.M. (Section 2.3.4) into the upper aquifer later in 1983. Sensors detected no increase in salt concentration of mine water from panel I (pers. comm. J. Gumbley, 1984 - S.C.M. geologist).

Six chemical analyses giving pH, Ca, Mg, K, Na, Fe, Zn and B contents of mine and surface water were completed for S.C.M. by the Chemistry Department, University of Waikato (Brenner, 1983). Analyses failed to provide any indication of hydraulic continuity because of limited sampling combined with a lack of regional groundwater chemistry data.

Tritium is a radioactive isotope found in water and is primarily used to determine water age (Stewart and Taylor, 1981). Tritium ratios ($3H/_H$) determined for S.C.M. by the Institute of Nuclear Sciences, D.S.I.R., are presented on Table 2.1. Conclusions drawn from this data by Taylor (1983) are;

1) the tritium ratios from surface water match ratios of recent precipitation .
2) the tritium ratios for water collected out of piezometers 6660 and 6664 (upper aquifer piezometers) are typical of springs and groundwater from shallow depths in pumiceous deposits of the Central North Island volcanic zone. The ratios suggest a mixture of water of various ages.

Table 2.1: Tritium Ratios of East Mine Water (Analyses determined for S.C.M. by Institute of Nuclear Sciences, D.S.I.R.).

Location	Sampling Dates		
	12 May 1983	18 September 1983	16 April 1984
Crosscut No. 1 South Section settling tank[1]	0.00±0.12	0.43±0.13	0.07±0.07
East Mine Discharge	0.26±0.11		
Piezometer 6660[2]	1.89±0.15		
Surface Water	3.35±0.13		
Piezometer 6664[2]		0.86±0.12	
North Headings Cross-cut No. 3		0.25±0.11	
Borehole 71[2]			0.08±0.07

1. The settling tank collects all mine water from the south headings, including panel 1.

2. For location of piezometers and borehole 71 see Figure 3.11. Borehole 71 is an incompletely sealed borehole encountered during mining and out of which inflow occurs.

3) the data from south headings discharge suggest entry of younger water into workings with the September 1983 value, and subsequent total absence of younger water with the April 1984 value.

Thus the tritium analyses are inconclusive with respect to the possible hydraulic connection between Tauranga Group aquifers and the mine workings.

2.3.3 Underground Inspections and Mapping

After the hostel subsidence mines rescue personnel inspected the panel 1 workings on three occasions. On the 20th January 1983, they discovered roof falls 1 to 8 (Figure 2.3) which prevented further inspection of the panel. After excavating an exploratory drive down the northwest panel margin, entry was made again in early February, 1983. During this inspection photographs were taken and are reproduced here as Figures 2.7 to 2.10. Full inspection of the panel was again prevented by roof falls 9 to 13.

On the basis of observations from the January and February underground inspections, McInally (1983a) drew the following conclusions:

1) The pillars in the areas examined are all intact and show no signs of 'weighting' or any significant deterioration.
2) The roadways and crosscuts are standing well and no major roof, rib or floor stability problems are apparent in any open roadway. Some minor heave and rib spall is present but this is not sufficiently developed to cause roof or pillar stability problems.
3) Access into one half of the panel is blocked by a series of roof falls. These falls are all at or very near junctions and there is no sign of stressing of roof or ribs right to the lip of the falls. The indications are that the falls could be failures at junctions with no extensive failures along roadways.
4) Most of the falls are showing no sign of water inflow and much of the material in the falls is

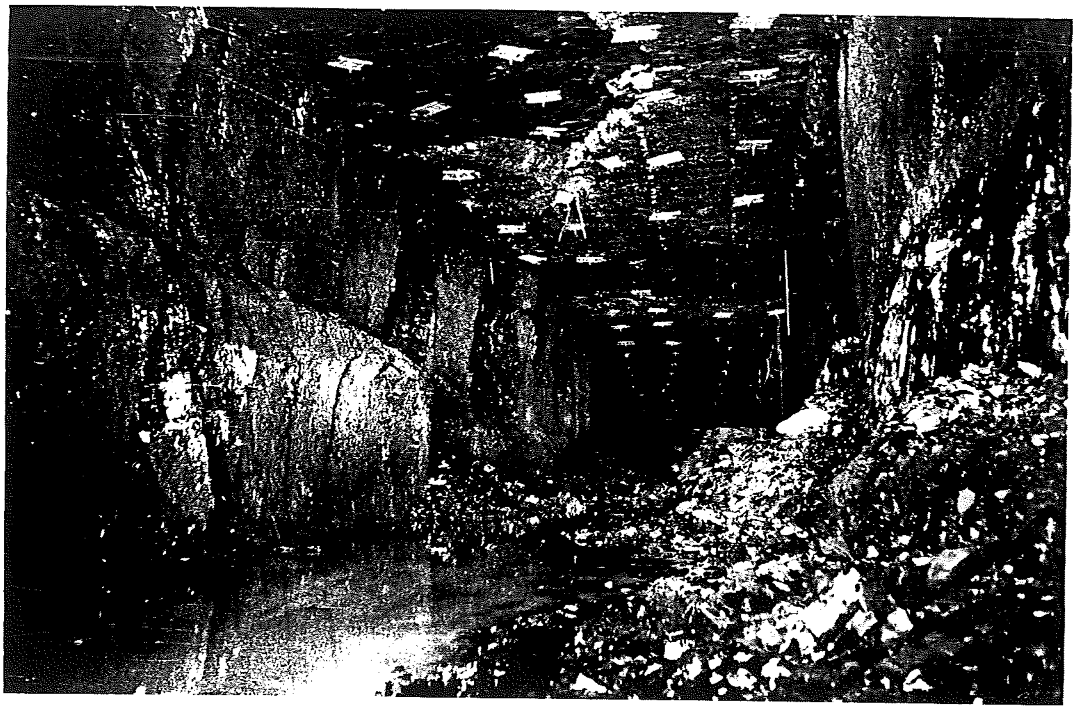


Figure 2.7: View northeast in cross-cut 22. Note the water on floor and minor rib spall. Cross-cut geometry is approximately 5 metres wide x 6 metres high. Rock bolts at c.1 metre centres extend 1.8 metres into roof.
(Note: Photographs 2.7 to 2.10 by S.C.M. Rescue Team, February, 1983).

Figure 2.8: Northeasterly view of roof fall No 9. Ladder on left was used for access from exploratory drive. Note the blocky nature of fallen debris.

Figure 2.9: View of pillar corner between roof falls 13B (left) and 13A (right).

Figure 2.10: View into caving chimney above roof fall 13A. Approximate distance to chimney roof is estimated at 3.0m. Note the 'ellipsoidal' caving geometry.

blocky and compact.

On the 10th April, 1983 an airblast resulting from sudden roof collapse blew out the stoppings which separate panel 1 from the belt haulage drive and the No.1 return (Figure 2.3). A subsequent underground inspection discovered roof falls 14 to 23.

Underground mapping of mine dimensions, geologic structure and pillar rib condition of the northeastern section of panel 1 by geomechanics staff (S.C.M.), is presented on Figures 2.11 to 2.13. Collection of this data was prompted by subsidence above panel 1, and was not part of normal mine working procedure.

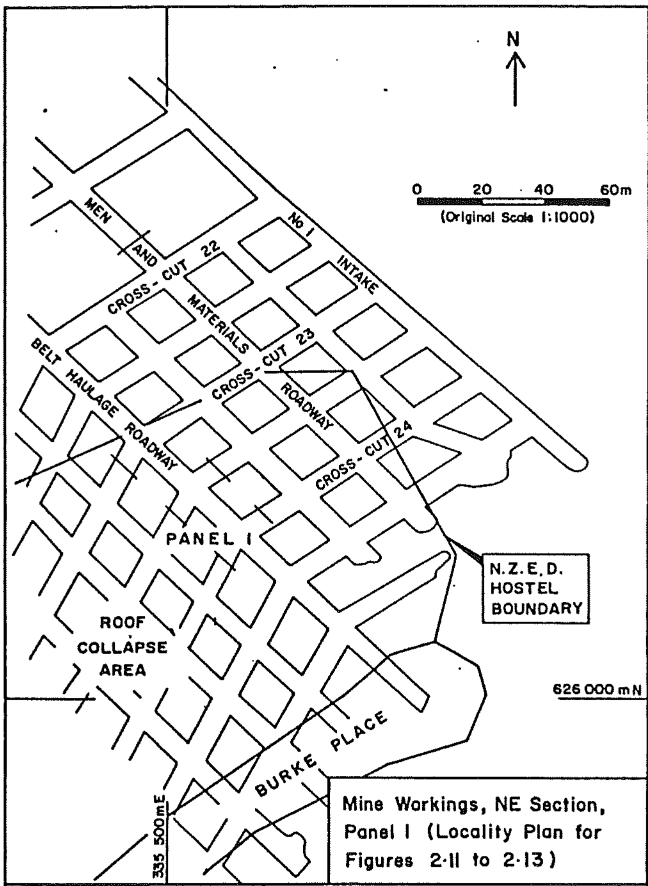
Figure 2.11 shows estimated roof heights to vary between 3.5m for "first-cut" drives to 6m where floor coal is extracted. Half of the pillars in the area are below the design dimensions of 15m x 15m (60m circumference).

Geologic structures mapped are shears and face cleat (Figure 2.12). The face cleats are near vertical with trends of 069^{o} to 090^{o}. These orientations are consistent with the average trends of 072^{o} to 088^{o} for the East Mine (Field, 1980). Shears trend 080^{o} to 095^{o} and 010^{o} (minor). The minor 010^{o} shear zones are of similar orientation to the N trending major faults of the area (Section 1.5.2.2). Shears with orientations 080^{o} to 095^{o} have similar trends to cleat direction.

Observations of ribs at the time of mapping (Figure 2.13) show that rib 'erosion' is most commonly concentrated in the upper and middle portions of the rib, extending up to 1.5m past the original cut face.

2.3.4 Subsidence fracture mapping and piezometer Installation

Surface investigations by S.C.M. include mapping of compressive and tensile subsidence features around the hostel in January 1983 (see Section 3.2.2) and installation of 10 piezometers during May 1983. S.C.M. piezometers monitor the upper aquifer in the Tauranga Group (see Section 3.5.3).



Mine Workings, NE Section, Panel I (Locality Plan for Figures 2·11 to 2·13)

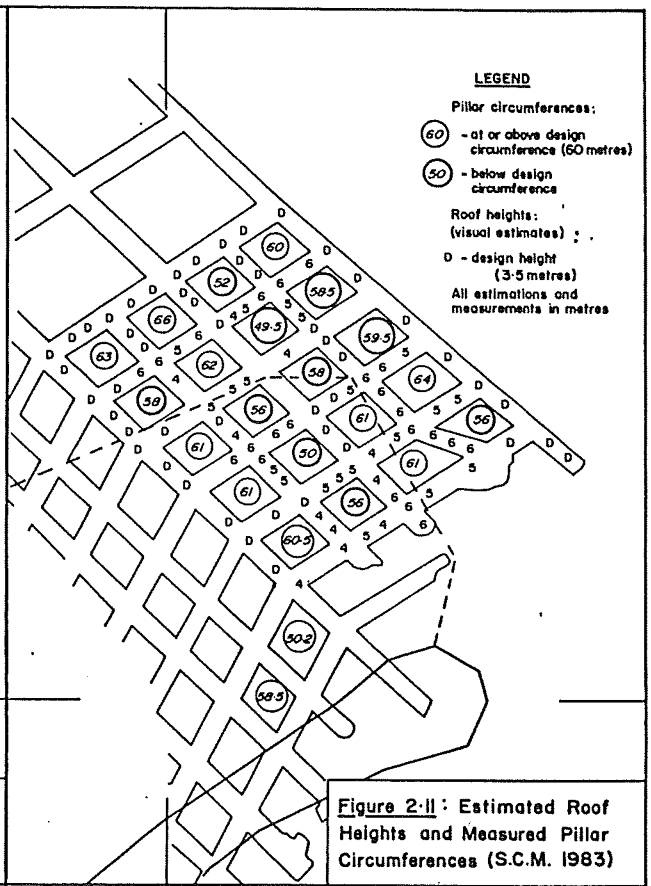


Figure 2·11: Estimated Roof Heights and Measured Pillar Circumferences (S.C.M. 1983)

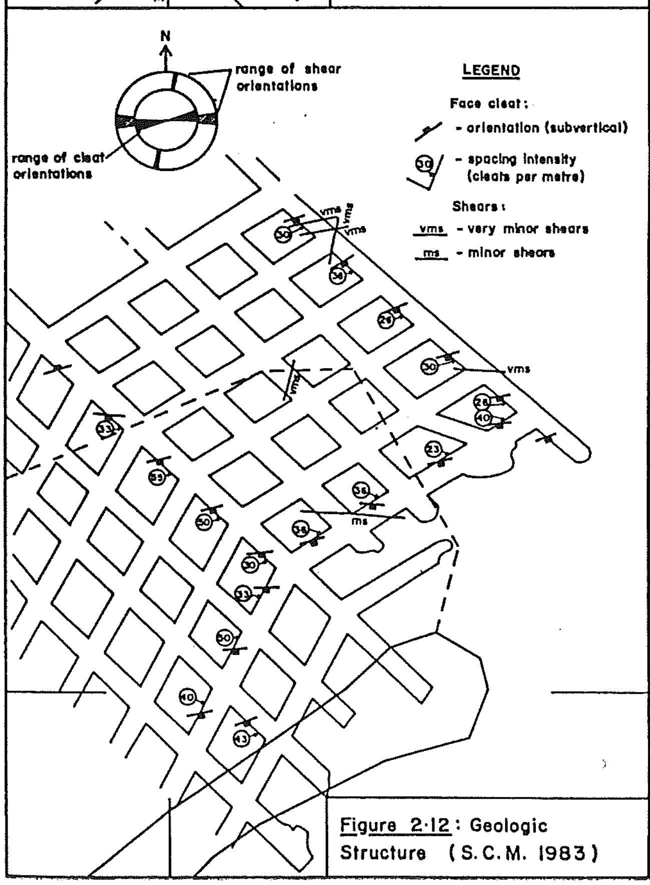


Figure 2·12: Geologic Structure (S.C.M. 1983)

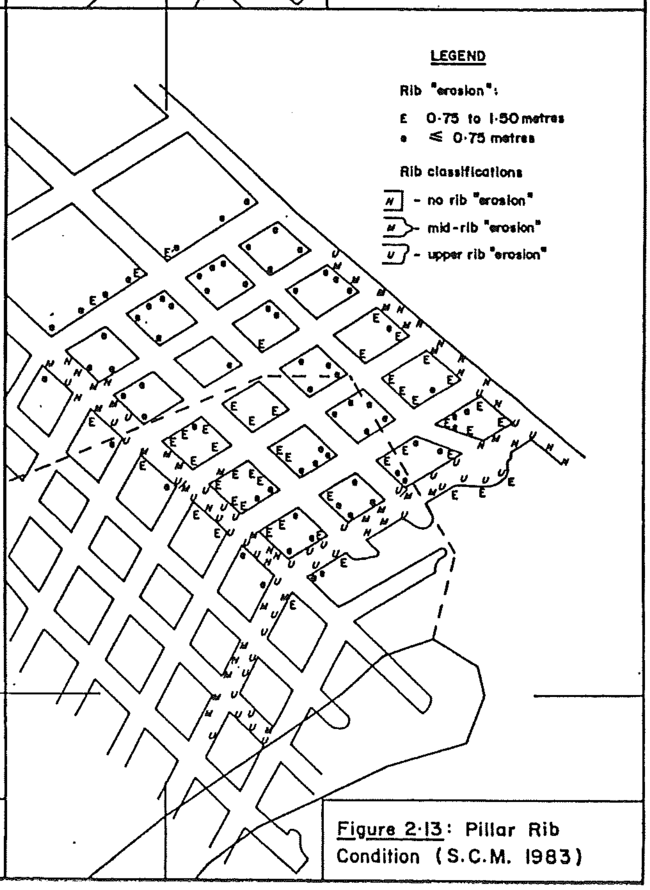


Figure 2·13: Pillar Rib Condition (S.C.M. 1983)

2.4 Ministry of Works and Development reports and investigations

From the 13th to 24th January 1983, M.W.D. drilled a cored borehole (BH 6599) at the hostel site (Figure 3.11) to help identify the cause of ground instability. The hole was confined to the Tauranga Group, its finishing depth estimated as 17m above the Te Kuiti-Tauranga Group contact. Core recovered from the top 10 to 15m showed no signs of shearing which would be consistent with slope failure causing the ground instability (Stewart, 1983). Core from BH 6599 has been relogged (see Appendix Two) and included in geological cross-sections (Figure 3.17 and 3.18) as part of this study.

M.W.D. laboratory investigations on BH 6599 core include grain size analyses, and determinations of bulk density, solid density, water content and porosity. These results are discussed in Chapter 4.

M.W.D. have provided advice to N.Z.E.D. regarding the hostel subsidence. Subsidence description, discussion of possible modes of failure and recommendations regarding site investigations and landuse are presented by Williams (1983, 1985).

2.5 Synthesis: Development of a tentative engineering geological site model.

From existing information a number of failure modes have been suggested to explain ground instability at the N.Z.E.D. Hostel (Depledge, 1983a; McInally, 1983a and Williams, 1983). Possible modes of failure can be divided into:

a) Those independent of mining activity;
   - i) slope instability,
   - ii) consolidation of upper Tauranga Group materials due to placement of landfill and drainage associated with residential development.

b) Those related to mining;
   - i) consolidation of lower Tauranga Group materials due to mining induced dewatering,

ii) mine floor failure (pillar punching),

iii) mine pillar failure,

iv) mine roof failure consisting of,

- roof collapse migrating to the ground surface
- or roof collapse causing material erosion of Tauranga Group silts, sands and gravels.

A model explaining the cause of the subsidence could also include any number of the above.

If slope failure were to have caused the instability, the area of subsidence would be typically located on the upper slope with a zone of uplift (accumulation) on the lower slope. All horizontal movement would be downslope. Survey monitoring (Figures 2.5 and 2.6) has shown the maximum area of subsidence to be on the lower slope with no evidence of a zone of uplift. L.S. marks E53 and E54 on the lower slope have moved towards the slope during the subsidence. Monitoring data is supported by M.W.D. drilling (Section 2.4) where no shear surface or zone of disturbance was identified in core.

Consolidation related to residential development is possible through either placement of landfill or establishment of stormwater drainage. Placement of landfill increasing surface loads as a failure mode for the hostel subsidence can be dismissed since the areas of maximum subsidence are located in natural ground (Figure 1.4). Stormwater drainage associated with residential development has reduced infiltration and recharge to the upper aquifer system (Section 1.5.4). Effects of reduced infiltration is considered negligible due to the regional extent of the upper aquifer system.

Roof collapse migrating directly to the surface produces 'crown holes' [1] and not the subsidence trough defined by survey monitoring. Based on bulking factors for coal measure rocks, St. George (1983) estimates the upper limit of void migration from roof collapse (discussed in Chapter Five) as approximately 10t (where t = mined thickness, 3.5 to 6.0m for panel 1). Panel 1 is 100 to 110m below the hostel and thus significantly greater than 10t.

1. See Appendix One.

The absence of Tauranga Group materials, both in the mine workings and in mine water discharge, provides further evidence of the restriction of caving to the Te Kuiti Group sequence.

Field evidence against mine floor and pillar failure are the underground inspection of the 20th January 1983, and the location of maximum subsidence related to phase I rapid movement. Figure 2.3 shows the workings inspected by S.C.M. which included part of the area of maximum subsidence as defined by survey data. As section 2.3.3 discusses more fully, no significant pillar or floor failure was observed. However, since the panel inspection was limited, pillar or floor failure cannot be completely dismissed as contributing to the observed settlement.

The engineering geological model considered most likely on the basis of field evidence alone is mine roof collapse allowing drainage and depressurising of aquifers at the base of the Tauranga Group (Figure 2.14). Aquifer depressurisation would cause consolidation of materials associated with the lower aquifer system. This model is suggested by:

1) the close proximity of the lower Tauranga Group aquifers to mine workings (Figure 1.7).
2) the underground observation of mine roof falls under the subsided area (Section 2.3.3).
3) the amount of water encountered during mining which suggests the presence of drainage paths from overlying Tauranga Group aquifers (Section 2.3.1).
4) the general timing of mine water discharge from panel 1 in relation to the observed subsidence.

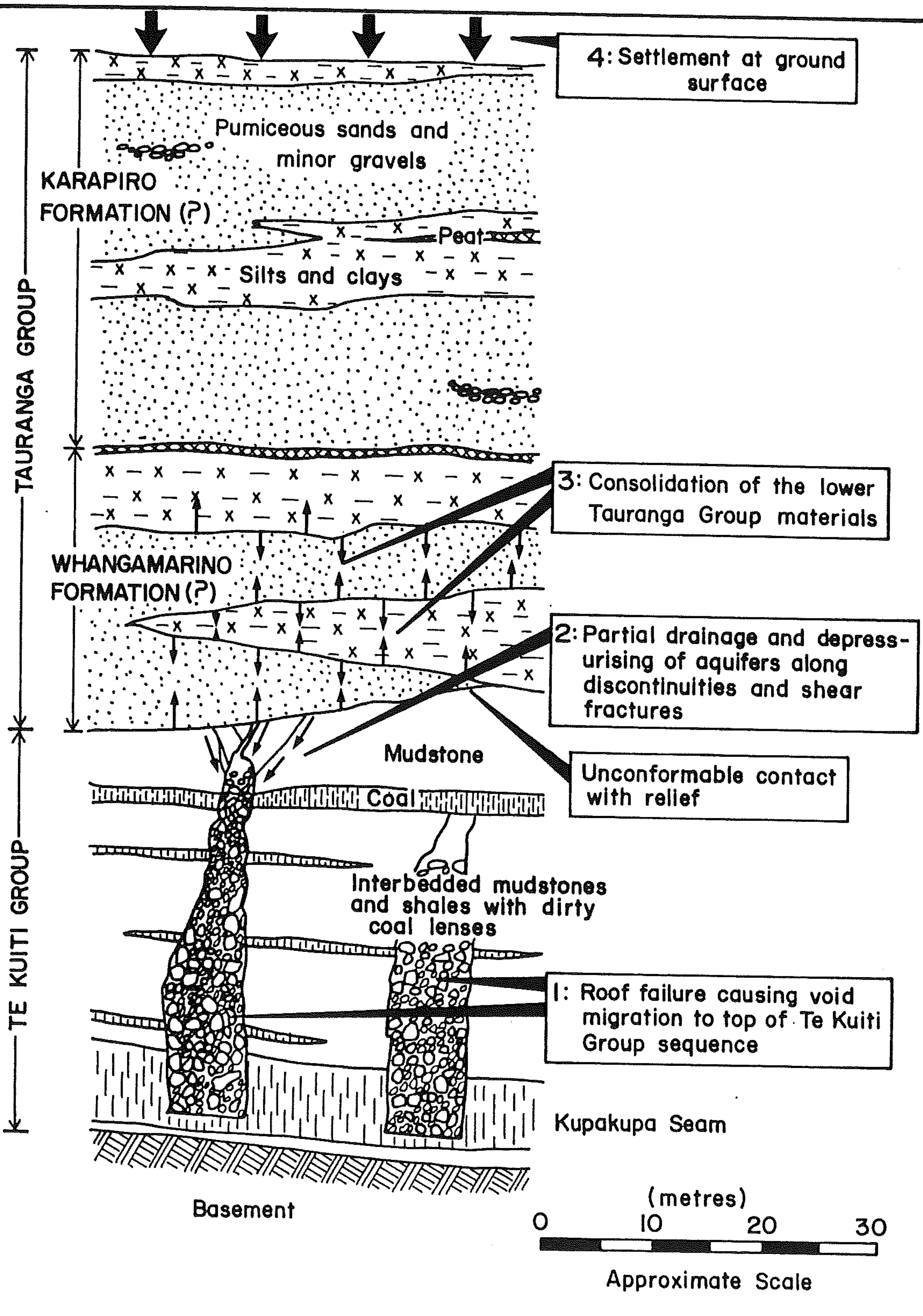


FIGURE 2·14: TENTATIVE ENGINEERING GEOLOGICAL SITE MODEL

CHAPTER III

FIELD INVESTIGATIONS

3.1 Site Investigation Objectives and Approach

Objectives for the hostel site investigation programme are:

a) to define subsurface geology in the lower part of the Tauranga Group in the area of subsidence.

b) to define relief on the Te Kuiti-Tauranga Group contact under the area of subsidence.

c) to recover core from Tauranga Group lithologies for laboratory testing.

d) to install piezometer monitoring in the lower aquifer system over adjacent, more recent workings where subsidence may occur in the future.

e) to measure in-situ compressibility of Tauranga Group materials using a static cone penetrometer.

The site investigation programme was carried out in two stages:

a) an initial reconnaissance stage which involved mapping of site geomorphology and surface strain features associated with the subsidence;and

b) a later more extensive phase of subsurface investigation by core and wash drilling, geophysical borehole logging, dutch cone static penetrometer soundings and piezometer installation.

The approximate cost of site investigation programme was $30,000.

3.2 Engineering Geological Mapping

The absence of surface outcrop in the hostel area restricted mapping to description of site geomorphology plus the location and description of surface strain features.

3.2.1 Site Geomorphology

Mapping of morphological features is based on a site 'walk-over' and interpretation from aerial photographs.

The site can be divided into two main landforms (Figure 3.1). The eastern part of the study area, where the hostel is located, exhibits relief up to 46 metres (a.s.l.) and is part of an extensive modified aggradation surface (Section 1.5.3). Modification of this surface is illustrated 150 metres north of the hostel with stream incision, and by the irregular nature of the northern and western slopes below the hostel, interpreted as being caused by degradation from a past meandering river system.

The western low lying area is generally flat and is part of an extensive younger fluvial terrace formed by overbank deposits from the Waikato River (Taupo Pumice Alluvium - Kear and Schofield, 1978). The western area has been significantly modified by urban development (See Section 1.4.3).

3.2.2 Surface Strain Features

3.2.2.1 Description

The distribution of surface strain features associated with the hostel subsidence is shown on Figures 3.2 and 3.3. Strain features were initially mapped by Stewart (1983) after phase I rapid subsidence then mapped as part of this study following phase II rapid subsidence.

Surface strain features are either tensile or compressive. Tensile features are most commonly distributed around the outer margins of the subsidence trough. During subsidence, fractures occurred in concrete paths (Figure 3.4), kerbing, tarseal (Figure 3.5), brick veneer (Figure 3.6) and natural ground (Figure 3.7). Fracture offsets generally range from a few to 100 millimetres. Orientations of fractures are commonly concentric and rarely radial to the locus of maximum subsidence (Figures 3.2 and 3.3).

Compressive features generally occur on the inner parts of the subsidence trough. Compressive strain is

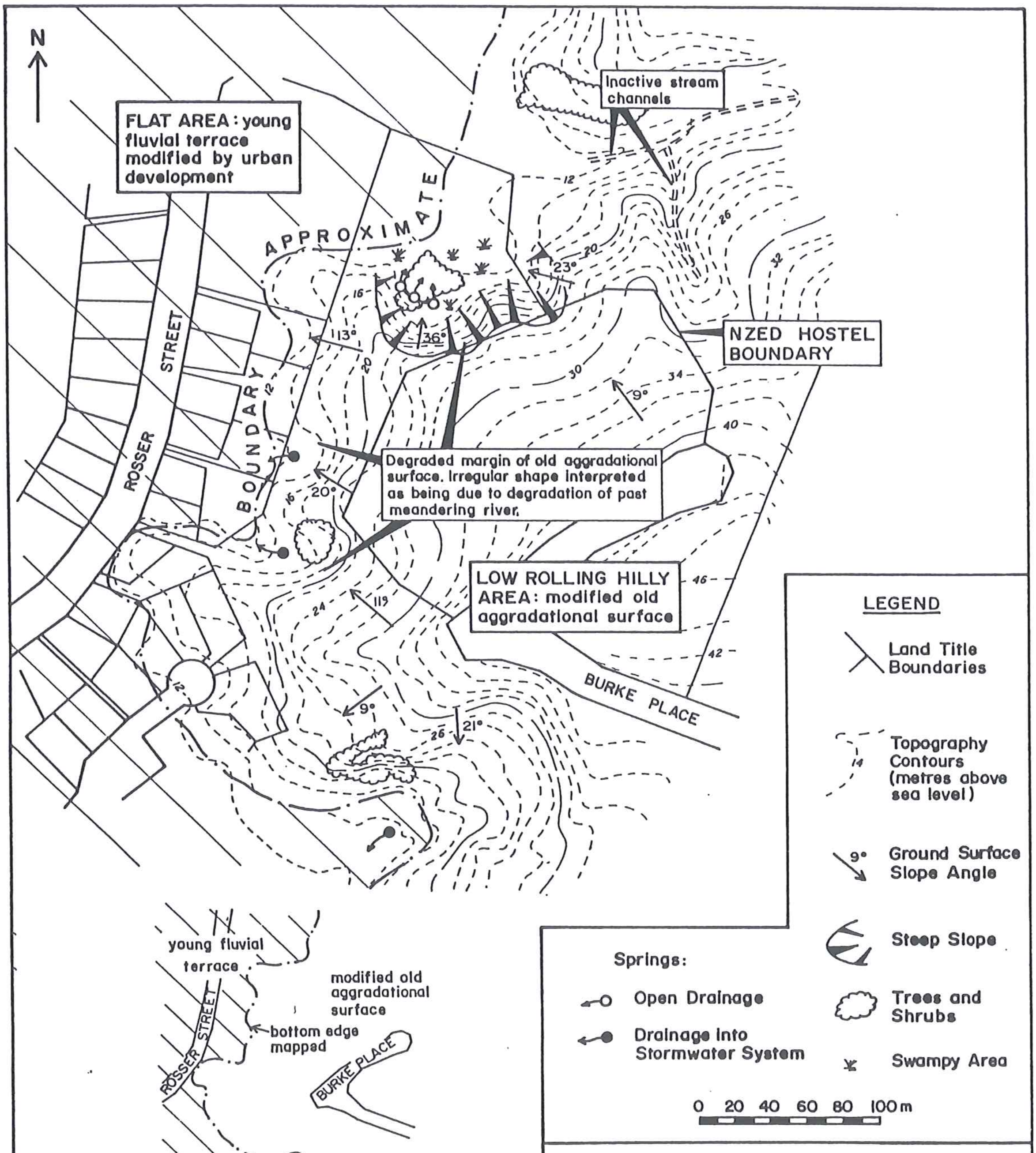


FIGURE 3·1 : SITE GEOMORPHOLOGY

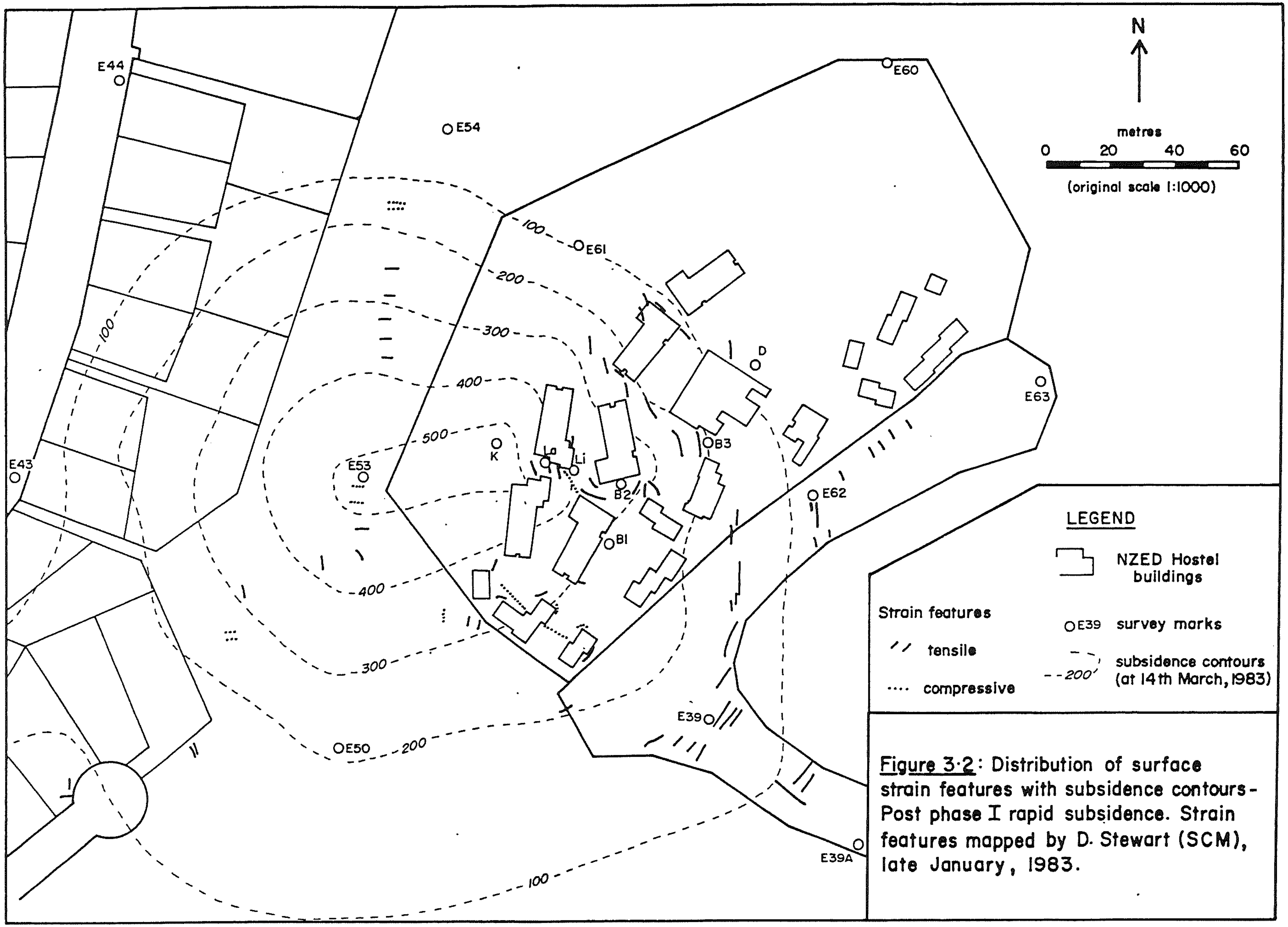


Figure 3·2: Distribution of surface strain features with subsidence contours - Post phase I rapid subsidence. Strain features mapped by D. Stewart (SCM), late January, 1983.

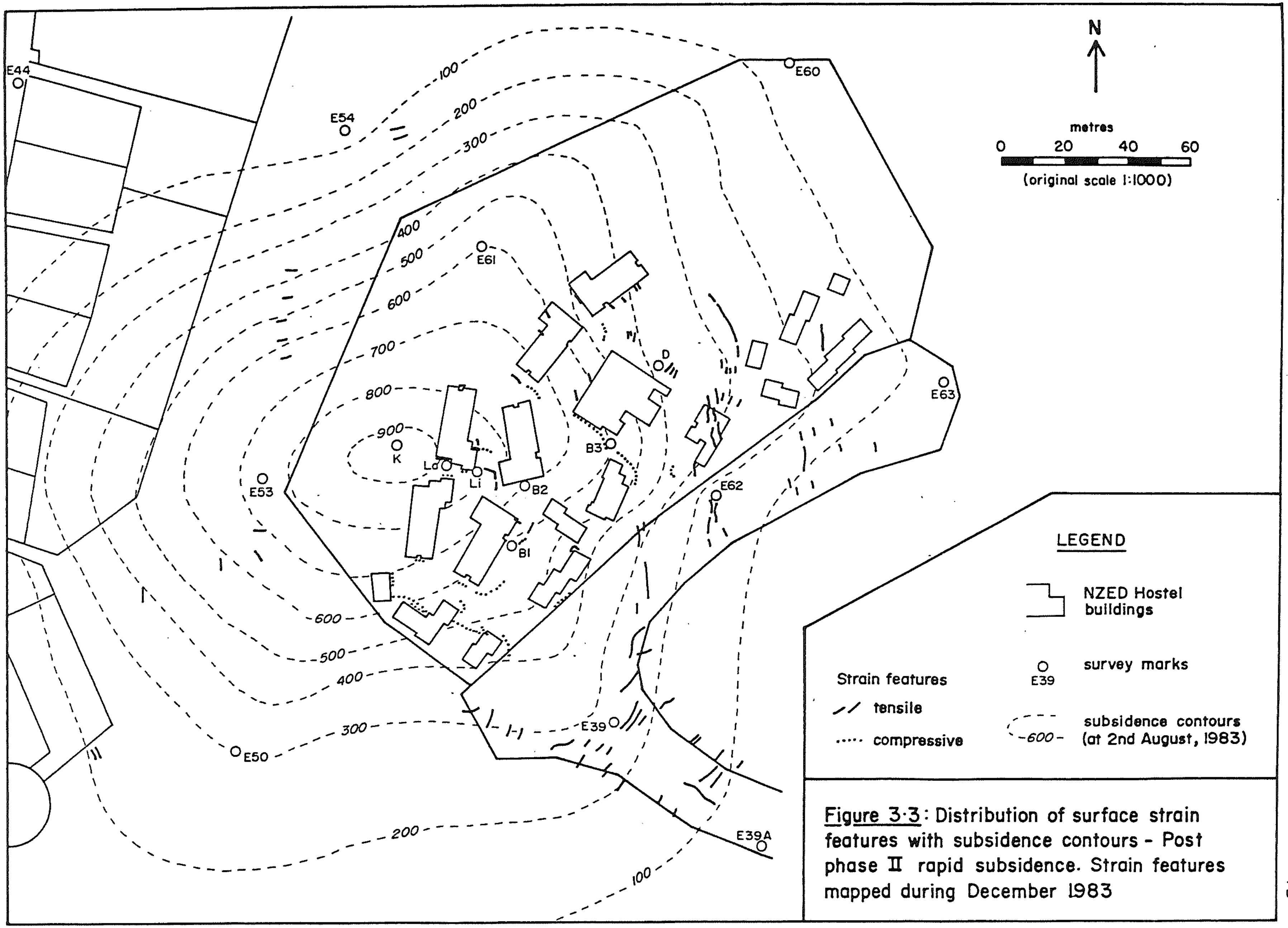


Figure 3·3: Distribution of surface strain features with subsidence contours - Post phase II rapid subsidence. Strain features mapped during December 1983

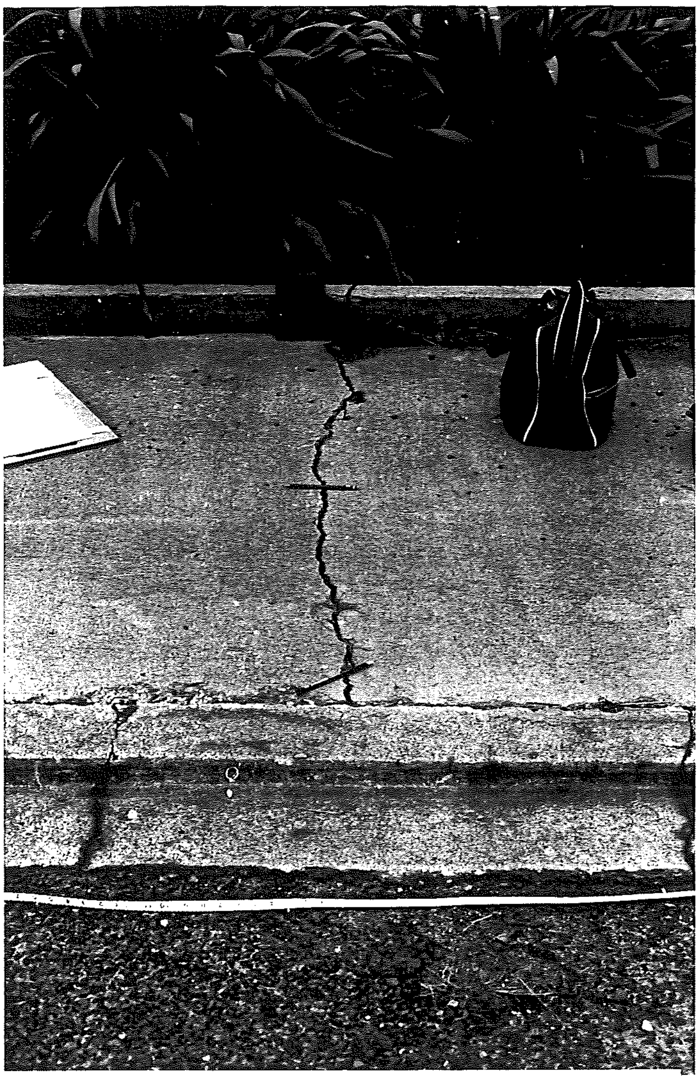


Figure 3.4: Tension fracture in concrete path and kerbing, Burke Place, January 1984. Fracture displacement ranges between 5 and 20 millimetres. Path fractures are common around the hostel and surrounding areas.

Figure 3.5: Tension fracture in kerbing and tarseal, Burke Place, January 1984. The most prominent fracture on Burke Place with an absolute displacement of 180mm measured between two originally adjacent points. Fracture is at kerb join.

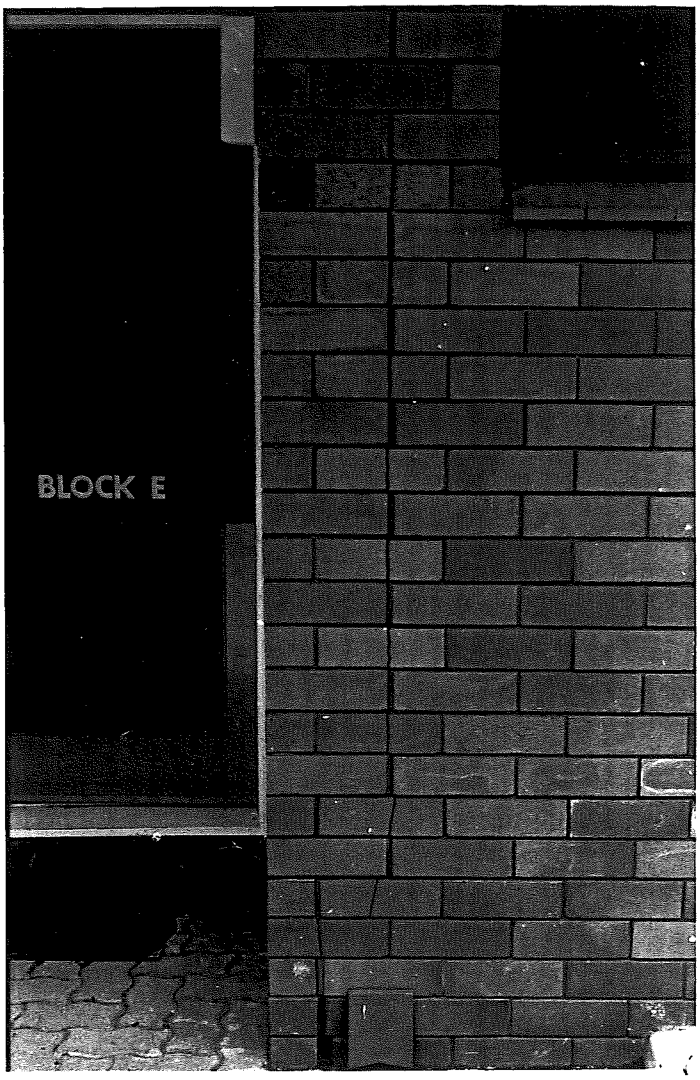


Figure 3.6: Tension fracture in brick veneer, Block E, N.Z.E.D. Hostel, January 1984. Fracture displacement is a few millimetres.

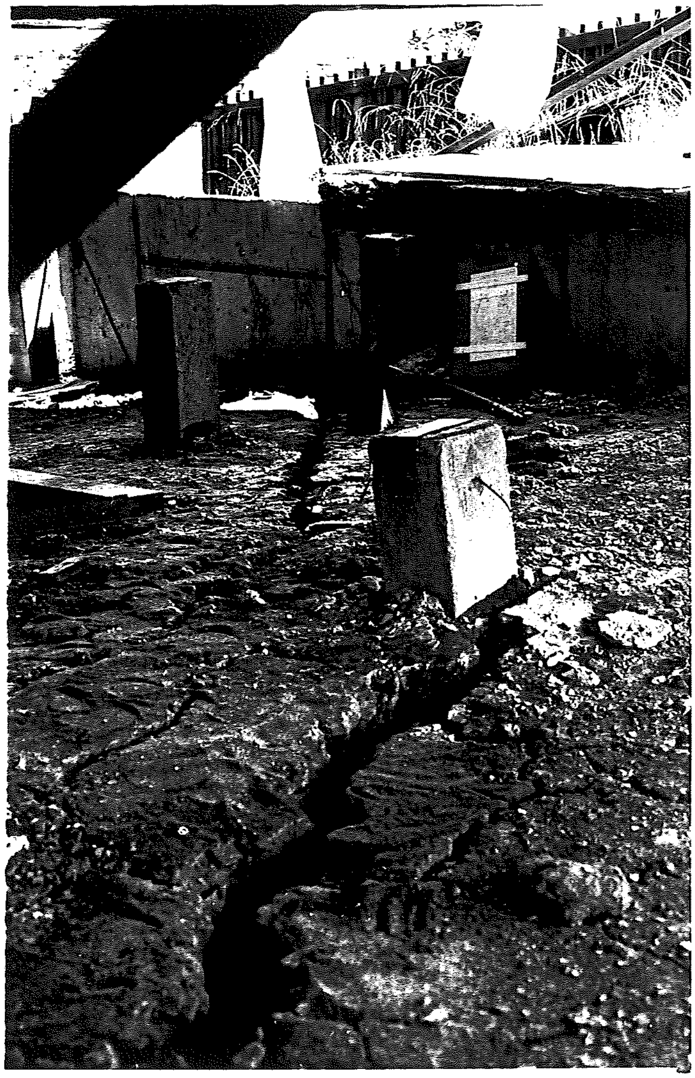


Figure 3.7: Tension fracture in natural ground below the Hostel Manager's residence, Januray 1984. Fracture displacement ranges between 20 and 50 millimetres. Note the extension of the fracture through the foundation wall in background.

Figure 3.8: Compression zone in concrete curbing and lawn between Blocks E and B, N.Z.E.D. Hostel, January 1984. Curbing on right overthrusts that on the left. Compression roll in foreground is marked by a bare area where lawn has been removed with mowing.

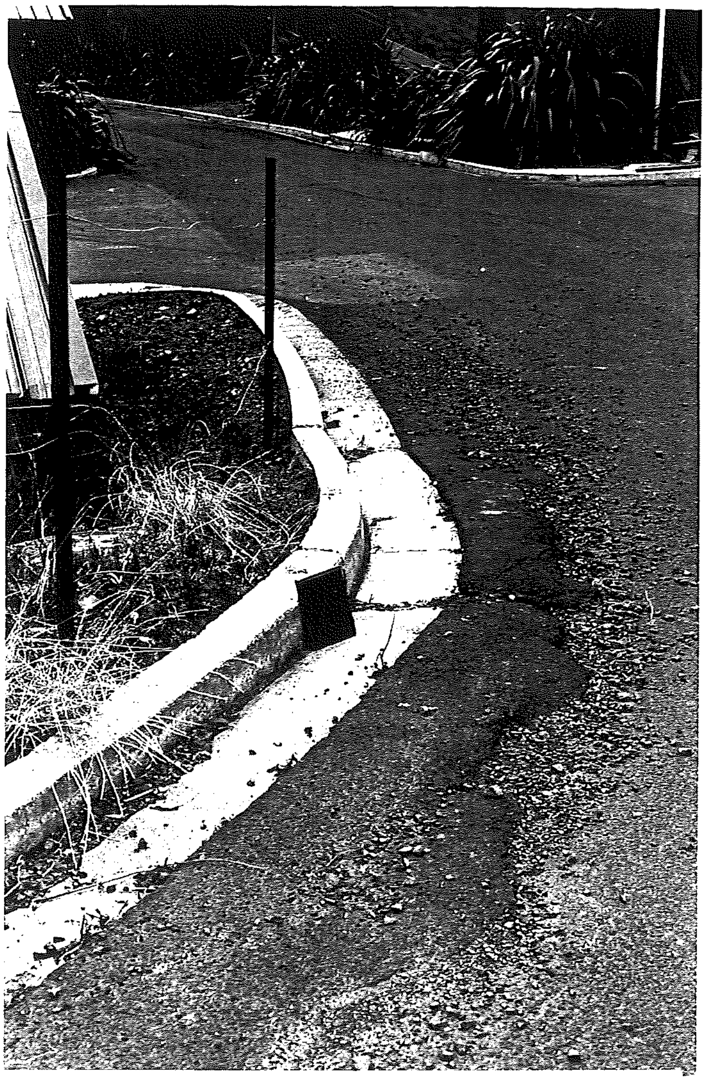


Figure 3.9: Compression zone in concrete curbing and tarseal, southern garage area, N.Z.E.D. Hostel, January 1984. Kerbing on left has been thrust to the right, causing a compression roll in tarseal.

expressed in brittle materials as upward buckling of footpaths and kerbing (Figure 3.8) or in more ductile materials as compression rolls in both tarseal (Figure 3.9) and natural ground. Vertical amplitudes of compression rolls generally range between 20 and 50 millimetres with a maximum measured amplitude of 160 millimetres. Orientations of the compressive features are generally either concentric or radial to the locus of maximum subsidence (Figures 3.2, 3.3).

3.2.2.2 Interpretation

Distribution of strain features with an outer tensile zone and an inner compressive zone is consistent with observations from other subsidence troughs in both North America (Gray et al., 1977) and the United Kingdom (N.C.B., 1975). An idealised subsidence trough showing this relationship is presented in Figure 2.2.

The northeasterly propogation of tensile fractures and extension of the central compression zone between January and December 1983 is indicated by survey data (Section 2.2) and marks the development of phase II rapid subsidence. Maximum zones of compression and tension defined by survey data are between E39-E53 and E39A-E39 respectively (Section 2.2). Both zones exhibit a concentration of surface strain features.

Surface strain features are most common in the eastern half of the subsidence trough. This apparent concentration is interpreted as being due to a combination of the effect of ground slope, which exaggerates the surface expression of strain, and a lack of good strain indicators in the northern and southwestern margins of the trough.

The predominant concentric orientation of strain features suggests that the principal horizontal strain direction is radial to the subsidence locus. The subordinate radial orientation of strain features, most common within the compression zone suggests a component of concentric horizontal strain during the development of the sub-circular subsidence trough.

3.3 Wash and Core Drilling

Brown Brothers Ltd were contracted by S.C.M. for the drilling programme. Rigs used included a tractor mounted Gardner Denver 200T and a truck mounted Failing Model 1250, the larger rig being required for coring (Figure 3.10).

The location of all boreholes including those from previous S.C.M. and M.W.D. investigations are shown in Figure 3.11. Borehole 6651, the main investigation hole, is fully cored and central to the subsidence area. Holes 6652, 6653 and 6657 are partially cored and wash drilled with 6654, 6655 and 6656 all wash drilled holes. All holes apart from 6657 extended through the Tauranga Group to the top of the Te Kuiti Group sequence. Sample dimensions for consolidation testing required 150mm diameter core to be recovered.

All core was logged as recovered. Samples from wash drilled holes were bagged every metre and logged later with the aid of geophysical data. Circulation loss and responses of rig to penetration are noted on the borehole logs. Detailed lithology logs and summary logs for each hole are presented in Appendix Two. Summary logs are used for cross-section construction in Section 3.8.

3.4 Geophysical Borehole Logging

3.4.1 Introduction

Borehole geophysics was included in the site investigation programme to aid geological and geotechnical correlation and interpretation of the Tauranga Group sequence.

In the proceeding section each logging tool used is briefly described according to its response. Following these descriptions, lithologic interpretations and geotechnical implications are summarised. A more comprehensive discussion of theoretical aspects, typical responses, uses, limitations, tool design and units of measurement is presented by Hoffman et al. (1982).

Figure 3.10: Brown Brothers Model 1250 'Failing' rig, recovering 150mm core from BH6651. Once core is extracted from triple tube barrel (about to be pulled away from mast), it is rolled into split p.v.c. (sitting on drill rod rack in foreground), logged, wrapped in plastic then stored under refrigeration.

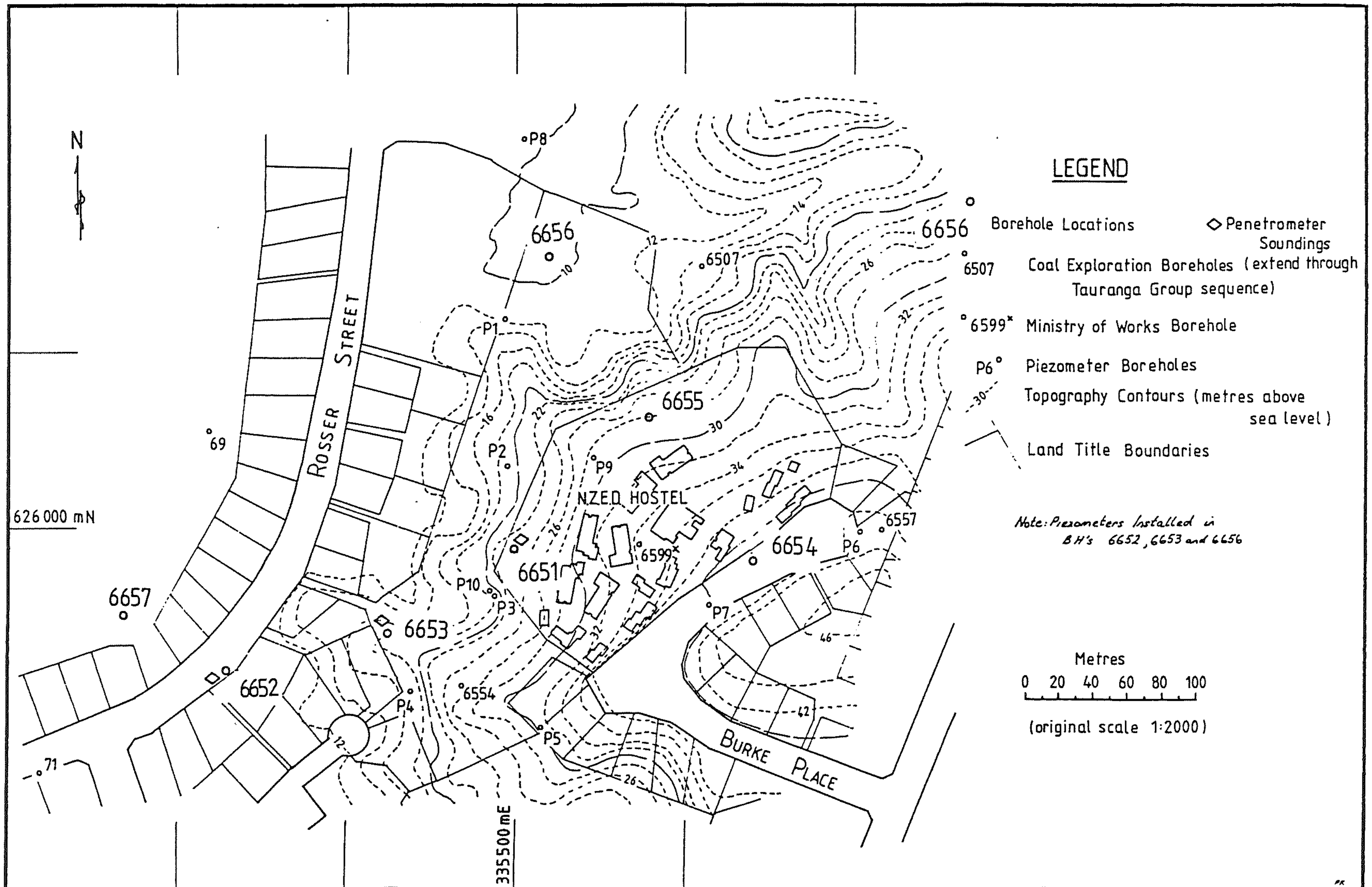


Figure 3·11: Locations of Boreholes and Penetrometer Soundings for Site Investigation Programme

A summary field data sheet showing log responses for BH6651 is presented on Figure 3.12. Log responses for other boreholes are presented in Appendix Three.

3.4.2 Log Responses

3.4.2.1 Natural Gamma Log

Gamma ray logging tools measure natural gamma radiation emanating from decaying isotopes (B.P.B., 1981). Common isotopes include potassium-40 (K^{40}), uranium-238 (U^{238}), uranium-235 (U^{235}) and thorium-232 (Th^{232}). Due to the very low concentrations of uranium and thorium in most areas (Levinson, 1974), the most important source of radiation is considered to be K^{40}.

On the basis of field observations, potential sources of K^{40} within the Tauranga Group sequence are acid volcanic glass, potassic feldspars (K,Na) $[AlSi_3O_8]$, illite clays $K_{1-1.5}Al_4$ $[Si_{7-6.5}Al_{1-1.5}O_{20}]$ $(OH)_4$ and jarosite $KFe(SO_4)_2(OH)_6$.

The natural gamma response is relatively unaffected by borehole caving or casing but does show amplification out of water (Figure 3.12). Natural gamma radiation is measured in A.P.I. units (American Petroleum Institute), which are empirical, and based on calibration test pits.

3.4.2.2 Gamma-Gamma Log

A gamma-gamma or density logging tool bombards the borehole walls with gamma radiation which is backscattered to a counter. The count rate reflects electron density which can be related to the material density (Hoffman et. al., 1982). Gamma-gamma logs are presented in terms of material density on a logarithmic scale.

Important considerations when interpreting gamma-gamma logs include the effects of borehole caving and high natural gamma radiation. In caved zones the logging tool incorporates drilling fluid density which results in an underestimate of material density (Figure 3.12). The logging tool counter is also sensitive to natural gamma

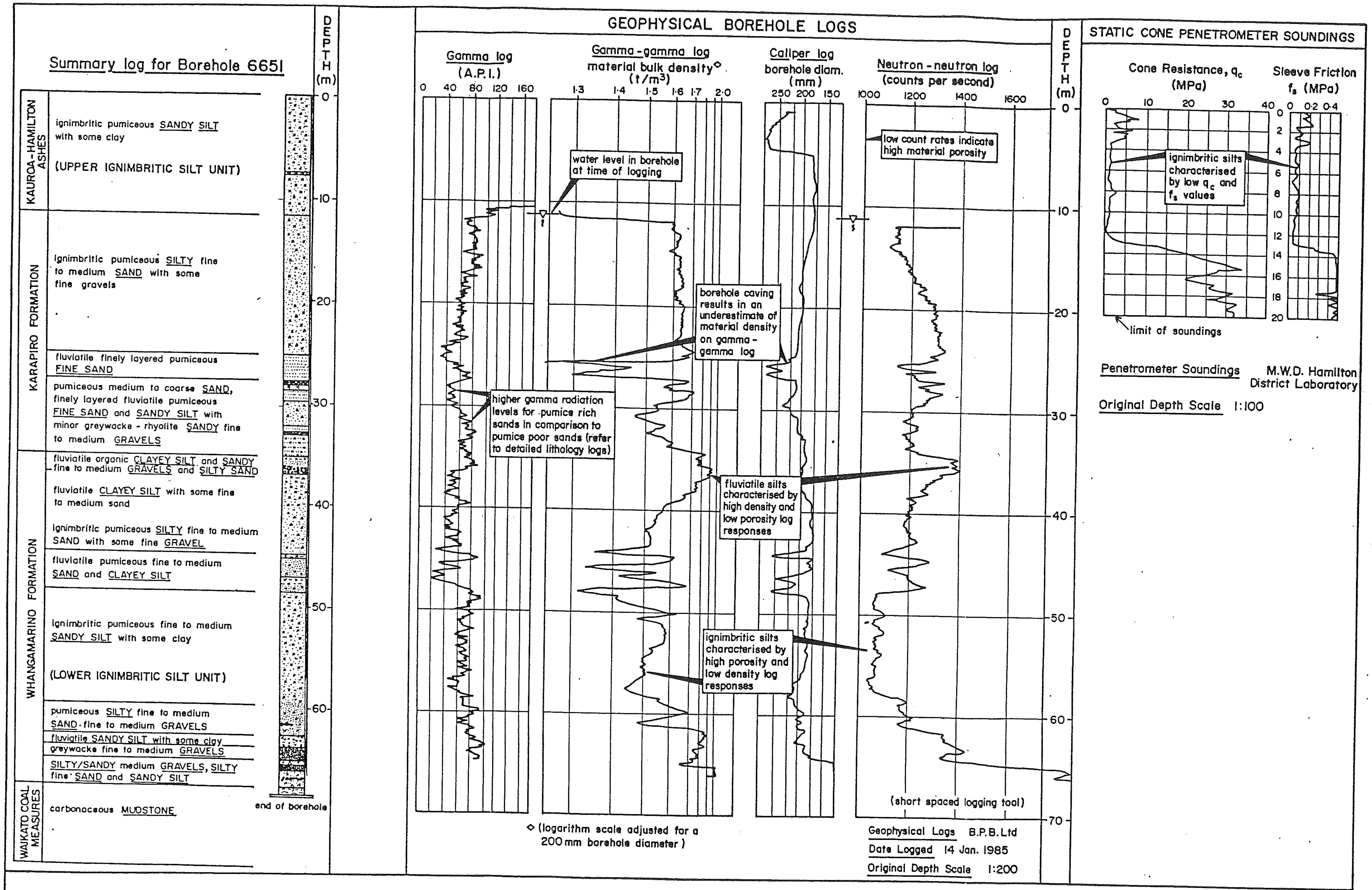


Figure 3·12: Field Data Logs for Borehole 6651

Fig. 3·12

radiation and when these levels are high, the material density response is exaggerated. Out of water a low density response is typical, reflecting air density (Figure 3.12).

3.4.2.3 Neutron-Neutron Log

The neutron-neutron tool emits high energy neutrons which bombard nuclei in the strata and borehole fluid. The tool's detector is only sensitive to low energy neutrons, therefore the response is determined by the effectiveness of the nuclei to dissipate neutron energy. Most efficient in reducing neutron energy is the hydrogen nucleus H^+, so the log is used as a direct measure of hydrogen content within its range of influence (Hoffman et al., 1982). Most hydrogen is present as water which includes H_2O in pore spaces and chemically bound water associated with clay minerals. Neutron-neutron logs are thus used as an indirect measure of water content and porosity.

Units of measurement are c.p.s. (counts per second) with high count rates indicating low H^+ content and low count rates high H^+ content. Casing reduces the count rate and the tool only operates below the borehole water level. A short spaced neutron logging tool was used for the hostel investigations.

3.4.2.4 Caliper Log

The caliper logging tool uses a mechanical arm to measure borehole diameter. The resulting caliper log identifies zones of caving and swelling which in turn are used for interpreting gamma-gamma logs. Since loose or poorly cohesive materials are prone to caving or swelling, the log can also be used as an indirect indicator of material strength.

3.4.3 Lithological Interpretation

Comparing log responses to detailed material descriptions from cored portions of boreholes, geophysical signatures unique to particular units can be determined.

These signatures are particularly useful for geological interpretation in zones of core loss and of washings from wash drilling. Determining material type from geophysical logs is an 'indirect' procedure based on an intuitive knowledge of material composition for the natural gamma log, density for the gamma-gamma log and porosity for the neutron-neutron log.

General observations based on geophysical data from cored portions of boreholes are:

- for fine grained materials (see Section 3.8.2 for material classification;

a) fluviatile sandy silts and clayey silts are characterised by high density and low porosity responses (BH6651[1], 34.6 to 35.0, 36.3 to 38.0 and 61.4 to 62.2, see Figure 3.12)

b) ignimbritic clayey silts and sandy silts are characterised by a higher porosity and lower density log responses (BH6651, 48.0 to 58.0, Figure 3.12).

- for coarse grained materials

a) caving is a common feature particularly with sands lacking fines (BH6651, 25.0 to 27.5) and at unit contacts (BH6651, 46.4 to 48.0, Figure 3.12).

b) higher natural gamma radiation levels are recorded for pumice rich sands in comparison to pumice poor sands (BH6651 - 28.7 to 31.4, Figure 3.12).

c) gravels are characterised by low porosity and high natural gamma log responses (BH6651, 35.4 to 36.2 aand 62.8 to 64.0, Figure 3.12).

- for peat;

a) peat horizons are characterised by low density and high porosity log responses (BH6652, 14.1 to 14.6 and BH6657, 1.0 to 3.0, Appendix 3).

Log responses to lithological boundaries are

1. For zone locations in boreholes, BH6651, 34.6 to 35.0 refers to material between depths 34.6 and 35.0 in borehole 6651.

generally dependent on the source-detector spacing, length of detector crystal and speed that the logging tool travels up the borehole (Hoffman et al., 1982). For this investigation positions of lithological contacts are determined on the basis of 'rules of thumb' as defined by Haines (1984). On the natural gamma log, the contact occurs one third of the distance along the slope from the high side to the low side. Contacts for the gamma-gamma log occurs at two thirds of the distance from the high side and for other logs the mid-point of the amplitude change mark lithological changes.

3.4.4. Geotechnical Implications

Determinations of in-situ semi-quantitative geotechnical data from geophysical borehole logging include material bulk density (gamma-gamma log) and porosity (neutron-neutron log).

Laboratory determined bulk densities, porosities and water contents (Section 4.3) are compared with gamma-gamma and neutron-neutron log traces for BH6651 on Figure 3.13.

Conclusions drawn from these comparisions are:

a) that in general a good correlation exists between laboratory and geophysically determined material bulk density.

b) that the neutron-neutron log in general reflects changes in actual porosity and water content. Low count rates are associated with highly porous materials (BH6651, 48.0 to 58.0) and high count rates with materials of low porosity (BH6651 - 35.0). The inverse relationship between porosity and neutron-neutron count rate is explained in Section 3.4.2.3.

3.5 Piezometers

3.5.1 Design and Installation

Selection of piezometer type was based on hydrostatic response time[1], cost, and simplicity of installation,

1. See Appendix One for definition of hydrostatic response time.

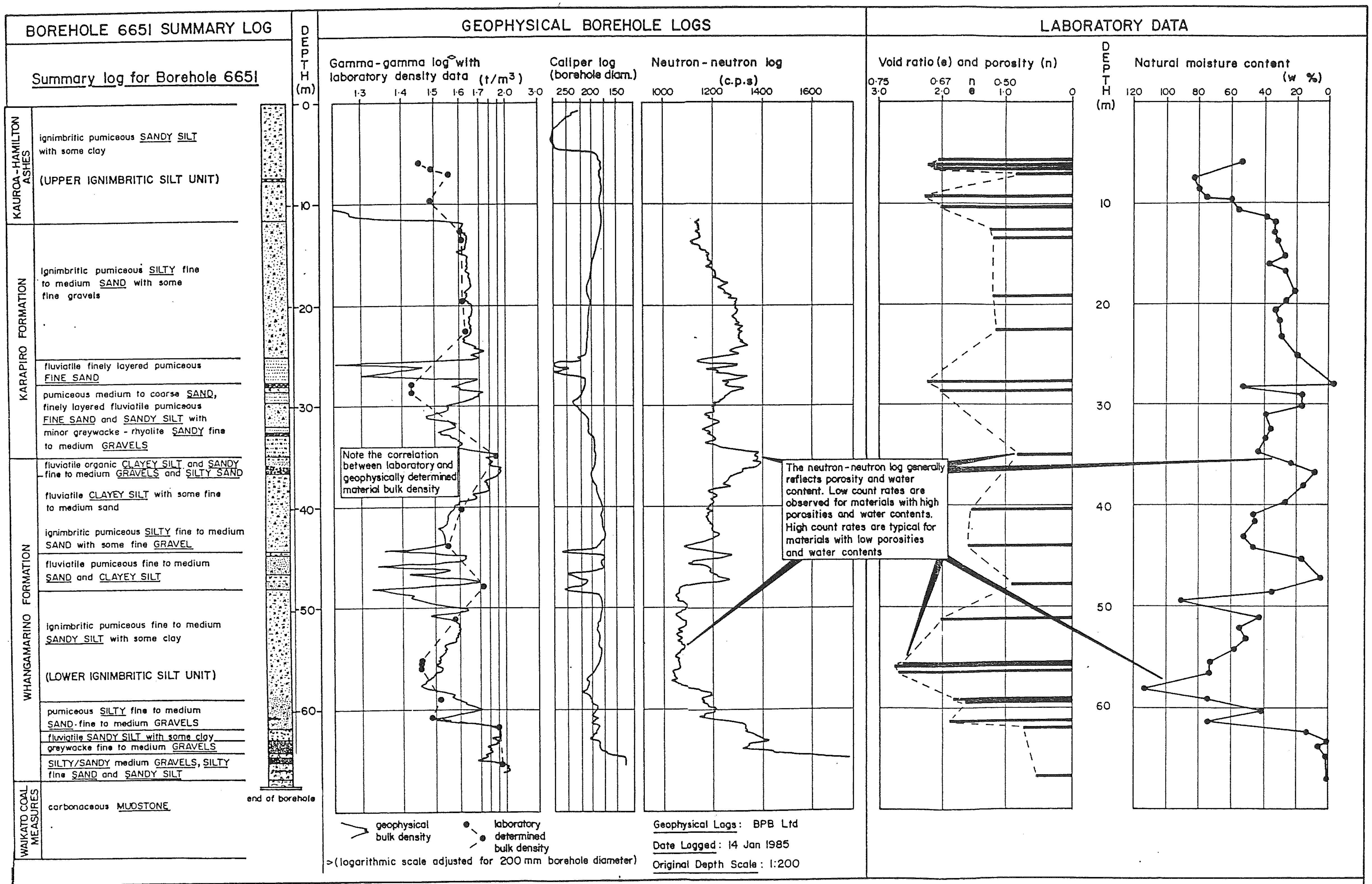


Figure 3·13 : Comparison of Geophysical and Laboratory Determinations of Geotechnical Data

Fig. 3·13

operation and maintenance. Terzaghi and Peck (1967 - page 672) graph the relationship between response time and soil permeability for different piezometers. Using this graph with a knowledge of expected aquifer permeabilities (10^{-4} to 10^{-5} m/s, Table 2.2), a Casagrande open standpipe piezometer (Casagrande, 1949) gave a 90% response time to increase in pore pressure of less than 3 hours. This piezometer is economical and simple to install and operate. The design of the installed piezometers are presented in Appendix 3.

Piezometers were placed at different levels in boreholes 6652, 6653 and 6656 for field permeability tests and monitoring of aquifers over adjacent mine workings away from the central area of hostel subsidence. Aquifer monitoring in areas where subsidence may occur in the future will allow field testing of the dewatering consolidation model (Figure 2.14) with observations of ground settlement and piezometer water levels.

3.5.2 Measurement of Field Permeability

3.5.2.1 Test Method

Falling head permeability tests were carried out on piezometers in boreholes 6652 and 6653. Tests required a tractor water wagon, stop watch and a water level indicator. Initially water was poured into the piezometer inducing an excess head. Horizontal permeability of the soil mass is determined from dissipation of excess head with time (Figure 3.14). Head fall was measured over a 20 minute period. A comprehensive description of the test method is presented by Sharp et al. (1977).

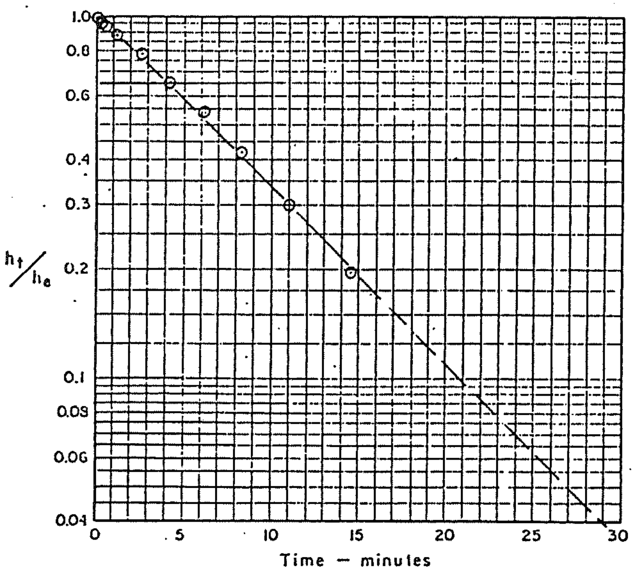
3.5.2.2 Results

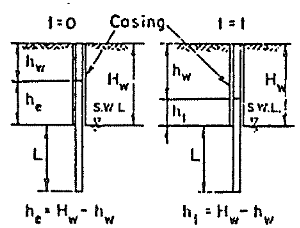
Test results are plotted on field sheets, an example is shown on Figure 3.14 . (Remaining field sheets are presented in Appendix Four). From plotted data horizontal permeability is calculated. Field permeabilities determined

FALLING HEAD TEST	Test N°	Date 30·1·85	Project HUNTLY SUBSIDENCE
	Engineer P.KELSEY		Borehole 6653-WHITE
Borehole co-ordinates		Collar elevation	
Depth to top of test-section 49·60 m		Length of test section, L 2·3 m	
Depth of static water level, H_w 17·22 m		Radius of borehole, r 0·075 m	
Excess head, h_e 17·22 m		Radius of standpipe or casing, r_c 0·02 m	

Time, T (min)	0	0·28	0·58	1·17	2·58	4·17	6·02	8·23	11	14·55					
Depth to water, h_w (m)	0	0·5	1·0	2·0	4·0	6·0	8·0	10·0	12·0	14·0					
Excess head, $h_t = H_w - h_w$ (m)	17·22	16·72	16·22	15·22	13·22	11·22	9·22	7·22	5·22	3·22					
h_t / h_e	1·00	0·97	0·94	0·88	0·77	0·65	0·54	0·42	0·30	0·19					

Head - time graph (slope of graph is S)



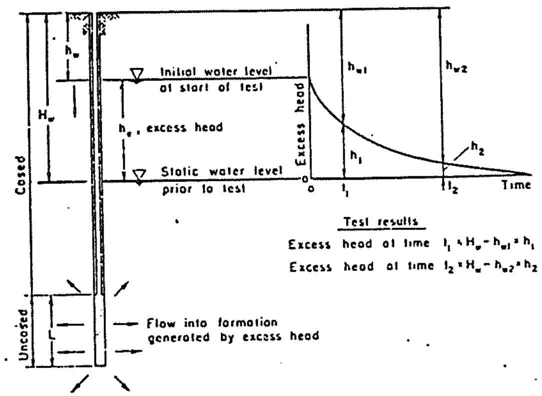


Calculations

Permeability $k = 0.133\,S\left(\frac{r_c^2}{L}\right)$ m/sec.

$S = \frac{\log_{10}\left(\frac{1.0}{0.04}\right)}{29_m} = 4.82 \times 10^{-2}$

$k = 1.11 \times 10^{-6}$ m/s



Permeability, $k = \frac{2.3 \log_{10}(h_1/h_2)}{t_2 - t_1} \cdot \frac{r_c^2}{2L} \cdot \ln(R/r)$ m/min.

$\ln(R/r)$ may be taken as 7

in which case

$k = 0.133\,S\,\frac{r_c^2}{L}$ m/sec

where S is the gradient of the log head time graph (Fig. B-3)

Figure 3.14: Principle of field falling head permeability test and calculation sheet (adapted from Sharpe et al., 1977).

as part of this project and S.C.M. investigations are presented on Table 3.1 Field and laboratory permeability data are combined in Section 3.8.4 for site hydrology.

3.5.3 Piezometer monitoring

All piezometers installed by this and previous investigations over the hostel site have been monitored by S.C.M.. To date no significant lowering in water levels have been recorded.

3.6 Dutch Cone Penetrometer Soundings

3.6.1 Test Procedure

The sounding device of a dutch cone static penetrometer consists of two parts, a conical point and a friction sleeve (Figure 3.15). The cone and sleeve are successively advanced into the soil by a static load. Resistance to penetration is measured in newtons (force) which is then divided by the areas of the cone and sleeve to produce cone bearing capacity (q_c) and sleeve friction (f_s) usually in units of MPa.

Penetrometer soundings are included in field investigations in an effort to measure in-situ soil compressibility within the Tauranga Group sequence. Correlation between lithological variation and penetrometer data is not attempted.

Tests were carried out by the M.W.D. Hamilton District Laboratory truck mounted penetrometer adjacent to boreholes 6651, 6652 and 6653 (Figure 3.11). Penetrometer data from these localities is presented on Figure 3.12 and in Appendix Three. Due to depth limitations of the penetrometer (maximum depth reached was 30 metres adjacent to BH6653), the data is restricted to the upper half of the Tauranga Group succession.

Table 3.1: Field permeability data for this and S.C.M. investigations from tests on N.Z.E.D. Hostel piezometers.

Piezometer	Filter Depth (metres below ground surface)	Material Description and Formation[3]		Horizontal Permeability (k_h - ms^{-1})
6652[1]				
- Blue	16.2 - 18.9	silty fine to coarse sand	Kp	4.81×10^{-7}
- Red	27.9 - 30.7	medium to coarse sand	Wg	1.77×10^{-6}
6653[1]				
- White	49.6 - 51.9	silty medium sand	Wg	1.11×10^{-6}
6658[2]	c.12.5 - 15.5[4]	silty coarse sand	Kp	c.3.6 $\times 10^{-6}$
6661[2]	c.18.6 - 22.6	fine to coarse sand	Kp	c.3.6 $\times 10^{-7}$
6663[2]	c.29.5 - 33.1	fine gravel and coarse sand	Kp	c.3.8 $\times 10^{-6}$
6664[2]	c.24.6 - 26.8	fine gravel and coarse sand	Kp	c.6.8 $\times 10^{-6}$
6666[2]	c.31.5 - 34.5	fine gravel and sand	Kp	c.4.1 $\times 10^{-6}$

1. This investigation.
2. S.C.M. investigation tests (Heu, 1984).
3. Formation abbreviations Kp - Karapiro Formation
   Wg - Whangamarino Formation.
4. S.C.M. filter depths based on incomplete information.

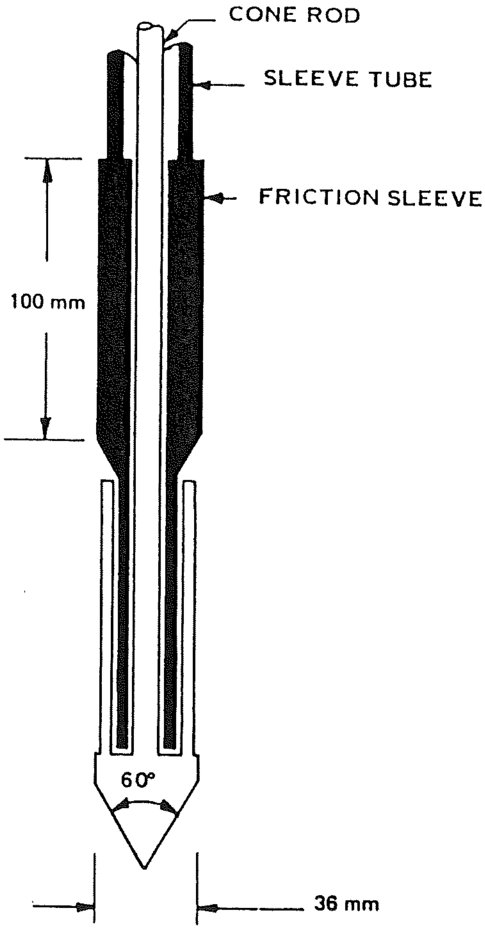


Figure 3.15: Conical point and friction sleeve for Dutch Cone Static Penetrometer (from Schuster and Krizek, 1978).

3.6.2 Penetrometer Evaluation of In-Situ Compressibility

3.6.2.1 Theoretical Consideration

For non-cohesive soils, compressibility has been related to cone resistance by:

$$C = \frac{1.5qc}{\bar{\sigma}_0} \quad \text{(Buisman, 1940)} \quad .... \quad \text{[Eqn. 3.1]}$$

where C = constant of compressibility

qc = cone resistance

$\bar{\sigma}_0$ = effective overburden stress at depth where qc is measured.

The compressibility constant can be then used to approximate settlement from a semi-empirical formula derived by Terzaghi-Buisman (Sanglerat, 1972):

$$\Delta h = \frac{h}{C} \operatorname{Ln} \left(1 + \frac{\Delta\bar{\sigma}}{\bar{\sigma}_0}\right) \quad .... \quad \text{[Eqn. 3.2]}$$

where Δh = settlement of an elemental layer of thickness h

$\Delta\bar{\sigma}$ = increase in effective stress at the same level of $\bar{\sigma}_0$

Equation 3.2 shows the inverse relationship between the compressibility constant and predicted settlement.

Sanglerat et al. (1969) developed equation 3.1 for application to cohesive soils replacing the constant 1.5 with α, a variable dependent on the nature of the soil. For overconsolidated soils (only considering overconsolidated soils on the basis of laboratory investigations described in Chapter 4), α can be determined by:

$$\alpha = \frac{2.3\ (1 + e_c)}{C_{cc}} \cdot \frac{\bar{\sigma}_c}{qc} \quad .... \quad \text{[Eqn. 3.3]}$$

where $C_{cc} = \dfrac{e_c - e'}{\log_{10}(100 + {}^{1}/_{\overline{\sigma}c})}$

and σ_c = preconsolidation pressure

e_c = void ratio corresponding to $\overline{\sigma}_c$

e' = void ratio at ($\overline{\sigma}_c$ + 100 kPa)

By using e' to calculate C_{cc} Sanglerat intends that values of α only be used to estimate settlements associated with increases in effective stress of about 100 kPa.

3.6.2.2 Discussion of Results

Values of α and C calculated for the overconsolidated ignimbritic[1] sandy silts (Kauroa - Hamilton Ash) and ignimbritic sands (Karapiro Formation) from BH6651 are presented on Table 3.2.

Laboratory testing data (Chapter 4) as presented on Table 3.2 identify two units of contrasting compressibility. The ignimbritic sandy silts and silty sands (samples from BH6651, 6.08 to 10.50) are characterised by high C_c values and low $\overline{\sigma}_c$ values in comparison to the underlying ignimbrite fine to medium sands (samples from BH6651, 12.85 to 19.30) with values of lower C_c and higher $\overline{\sigma}_c$. Cone resistance directly reflects this contrast with low qc values through the upper highly compressible unit and high qc values through the underlying sands. Consistently low qc values for the upper horizon (see Figure 3.12, qc values over 3.5 to 12.5 metres depth) indicates that the unit is highly compressible throughout its thickness.

Table 3.3 shows values of α calculated for a wide range of soil materials from a French study based on 600 samples (Sanglerat, 1972). Values of α evaluated for samples of BH 6651-6·08 to 10·50 m average at 1.7, below the range determined by the French study for

1 See Section 3.8.2 for material classification.

Table 3.2: Dutch cone compressibility α values based on one-dimensional consolidation testing from BH 6651.

	Depth (m)	Material Description	C_c	$\bar{\sigma}_c$ (kPa)	$\bar{\sigma}_0$[1] (kPa)	qc (kPa)	α	C
KAUROA-HAMILTON ASHES	6.08	ignimbritic sandy silt (MH)	1.236	245	91	1014	1.5	16.7
	6.45	ignimbritic sandy silt (MH)	0.967	365	96	919	2.7	25.9
	7.21	ignimbritic sandy silt (MH)	1.012	330	108	1297	1.8	21.6
	9.83	ignimbritic silty fine-medium sand (MH-SM)	1.396	210	147	1149	1.0	7.8
	10.50	ignimbritic silty fine-medium sand (MH-SM)	0.876	180	157	973	1.4	8.7
KARAPIRO FORMATION	12.85	ignimbritic fine-medium sand (SM-SW)	0.213	670	192	3041	4.8	76.0
	13.59	ignimbritic fine-medium sand (SM-SW)	0.156	680	197	15,000	1.7	129.4
	19.30	ignimbritic fine-medium sand (SM-SW)	0.133	660	233	30,270	0.8	103.9

[1] Effective overburden stresses calculated from boundary conditions described in Appendix 6

C_c = Compression Index

$\bar{\sigma}_0$ = Effective overburden stress

$\bar{\sigma}_c$ = Preconsolidation pressure

qc = Cone resistance

C = Constant of compressibility

Table 3.3: Values of the α coefficient for clayey and silty soils (Sanglerat, 1972).

CL – low-plasticity clay:		
	$q_c < 7$ bar	$3 < \alpha < 8$
	$7 < q_c < 20$ bar	$2 < \alpha < 5$
	$q_c > 20$ bar	$1 < \alpha < 2.5$
ML – low-plasticity loam:		
	$q_c < 20$ bar	$3 < \alpha < 6$
	$q_c > 20$ bar	$1 < \alpha < 2$
OH – very plastic clay *MH–OH – very plastic loam:*		
	$q_c < 20$ bar	$2 < \alpha < 6$
	$q_c > 20$ bar	$1 < \alpha < 2$

MH-OH soils with qc <2MPa. The low α average is interpreted as being due to the highly compressible nature of the material. Sand α values for samples BH6651, 12.85m to 19.30m, although limited, extend over a wide range (0.8 to 4.8), a feature also observed with the French data. Also presented on Table 3.2 are C values evaluated using Sanglerat's modified version of equation 3.1. For the upper highly compressible unit the low C values when substituted into equation 3.2 produce the expected high values of estimated settlement.

Penetrometer data is not incorporated into the settlement analysis (Chapter 5) because of critical importance to the dewatering model (Figure 2.14), is the consolidation behaviour of the lower Tauranga Group, out of the range of penetrometer soundings.

3.7 Mine Roof Fall Bulking Assessment

Since panel 1 under the hostel was sealed at the time of this investigation, underground observations were restricted to assessing the bulking factor (volumetric expansion) of coal measure materials associated with roof falls.

Bulking is determined by the expression:

$$B = (Vc - Vo)/Vo \qquad \text{(Dunrud, 1984)}$$

where B = Bulking factor
Vo = Volume of rock before caving
Vc = Volume of rock after caving

A roof fall from crosscut 13, panel 4 was chosen for the study. The fall, accessable from all sides was measured with a tape and compass. A plan and sections through the collapsed area are presented on Figure 3.16.

Volumes are approximated using a modifed version of Simpsons Rule (Berkman, 1982-p.187). The irregular section areas required for Simpsons Rule are estimated using a polar planimeter.

Bulking at this site is calculated at 28.7% (c.30%). This figure is in agreement with McInally (1983a) who uses a 30% bulking value for calculating maximum caving heights above panel 1. Discussion of bulking factors with reference to void migration are presented in Chapter 5.

Factors to note from mapping of the roof fall in crosscut 13 are that:

a) the fall occurs at the intersection of two mine drives (also observed for roof falls in panel 1 below hostel - Figure 2.3).

b) chimney development is partially defect[1] controlled as suggested by
   - the intersection of two vertical shears in the collapse area
   - the common occurrence of slickensided blocks in the debris pile
   - bedding planes exposed in the southwest section of the chimney

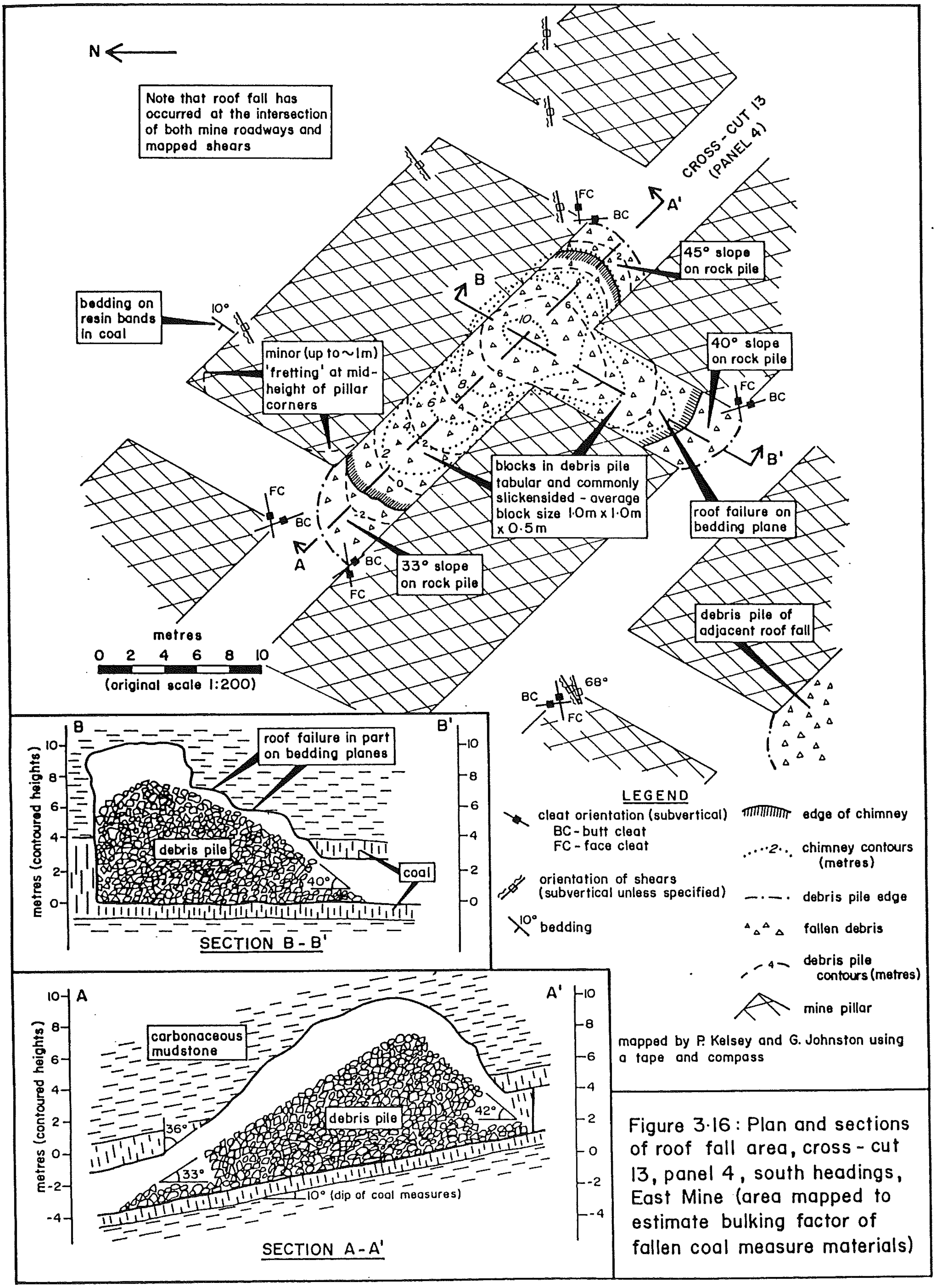


Figure 3·16: Plan and sections of roof fall area, cross-cut 13, panel 4, south headings, East Mine (area mapped to estimate bulking factor of fallen coal measure materials)

3.8 Synthesis: Hostel Site Geology and Groundwater Hydrology

3.8.1 Introduction

This synthesis presents an engineering geological description of the Tauranga and Te Kuiti Group sequences encountered during drilling. The description is based on borehole logs presented in Appendix Two from which large scale cross-sections (Figures 3.17 and 3.18)[1] are constructed through the hostel area. Site hydrology is described in terms of the large scale cross-sections, field and laboratory permeability determinations and piezometric data.

3.8.2 Material Classification

Rock and soil material field descriptions are based on a classification scheme proposed by Bell and Pettinga (1983). This classification is preferred to others (N.Z.G.S., 1985; I.A.E.G., 1981) because of its conciseness and 'graphical' presentation, allowing rapid field logging of samples from core and wash drilling.

Laboratory investigations (see Chapter 4) of Tauranga Group materials demonstrates a relationship between soil compressiblity and mode of deposition. Due to the importance of soil compressibility to the tentative engineering geological model (Figure 2.14), modification of the Bell and Pettinga scheme for soil materials in terms of their origin is required.

Geological evidence indicates that the Tauranga Group sequence consists of both ignibmbritic and fluviatile deposits (Section 3.8.3.3). When these deposits are distinguished within the sequence, the soil material descriptions are preceded by either 'ignimbritic' or 'fluviatile'. Where the depositional mode cannot be determined, for example some sand units sampled by wash drilling, the preceding adjective is omitted from the description.

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1. Figures 3.17 and 3.18 are in map pocket at back of thesis.

The term 'ignimbritic' as used for description refers to deposits that are formed by large scale, generally rhyolitic, pyroclastic volcanism (Wilson and Walker, 1982). 'Fluviatile' when used in descriptions refers to deposits that are formed by river action.

The advantages of using genetic qualifiers to textural descriptions over introducing classification schemes for each type of deposit (for example adopting the engineering geological classification of ignimbritic deposits by Prebble, 1983) are simplicity through lack of double nomenclature and ease of detailed textural descriptions. Preceding a soil description with a genetic qualifier was adopted by Paterson (1977) who described "ignimbritic silty sands" in the Poutu Tunnel, Tongariro Power Development.

3.8.3 Site Geology

3.8.3.1 Te Kuiti Group Materials

All boreholes of this investigation, apart from BH6657, extend through the Tauranga Group sequence into the top of the Te Kuiti Group succession. The top of the Te Kuiti Group sequence is commonly marked by a 0 to 2.0 metre thick highly weathered silty clay (CH)[1]. The clay contains rare rootlets and shows a gradational contact with the underlying unweathered, strong to very strong, dark olive and greyish brown, finely layered carbonaceous mudstone.

On the basis of colour and carbonaceous content the mudstone is interpreted as being part of the Waikato Coal Measures. Levelling data from the mine floor of panel 1 indicate that the coal measures underlying the hostel generally dip 8^{o} NW. In the southern section of panel 1 this orientation changes to 8^{o} N. Details of geologic structure mapped in the northeastern section of panel 1 by S.C.M. is summarised in Section 2.3.3.

The absence of other Te Kuiti Group formations over panel 1 indicate that erosion extended into the Waikato Coal

1. Abbreviations according to the Unified Soil Classification System.

Measures prior to the deposition of the Tauranga Group sequence (Figure 1.7).

3.8.3.2 Te Kuiti Group-Tauranga Group Contact

One of the principal objectives of this study is to determine relief on the Te Kuiti-Tauranga Group contact by meams of drilling. This contact provides a geometric constraint to thickness of Tertiary overburden over mine workings (Section 1.5.5) which is important in terms of void migration resulting from roof falls (Figure 2.14). Structure contours for the Te Kuiti-Tauranga Group contact and isopachs showing coal measures material thicknesses above the mine workings are shown in Figure 3.19.

Paleorelief on the contoured surface is dominated by a buried hill (-10m. R.L.) to the east gently sloping (c. 8^{o}) to a buried valley in the west (-45m. R.L.). On this surface drilling has delineated a east-west striking minor buried valley. Constructed isopachs show that coal measure material thicknesses range from 35 to 50 metres above panel 1. The significance of these thicknesses in terms of void migration resulting from roof falls is discussed in Chapter 5.

3.8.3.3 Tauranga Group Materials

Soil materials of the Tauranga Group consist of a 50 to 70 metre interlayered sequence of sands, silts and gravels with minor clay and peat. The sequence is highly pumiceous and typically well graded (poorly sorted). Lithological field relationships are generally complex with lateral and vertical variations over short distances (Figures 3.17 and 3.18).

A. Ignimbritic deposits

Ignibritic deposits are generally either silts or sands. Engineering geological descriptions of these materials are presented in Appendix Two.

Ignimbritic sands are identified on the basis of

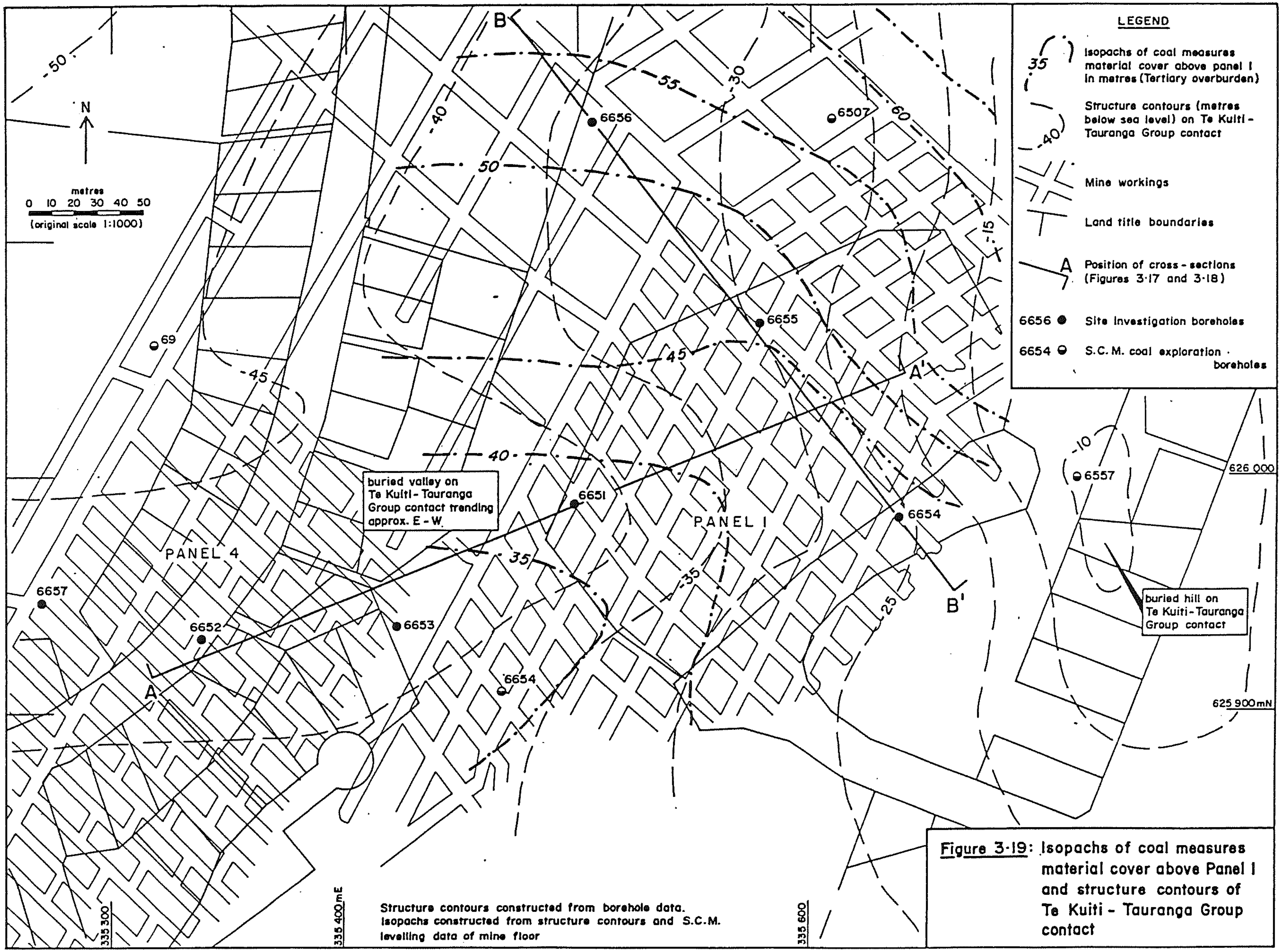

Figure 3·19: Isopachs of coal measures material cover above Panel I and structure contours of Te Kuiti - Tauranga Group contact field texture and rhyolitic 'composition' (pumice rich with lesser amounts of quartz, feldspar and rhyolite rock fragments). These sandy deposits are generally well graded (poorly sorted), massive, lack internal structure and contain charcoal and flattened pumice fragments (Figure 3.20). Two laterally extensive units are identified within the Tauranga Group sequence (Figures 3.17, 3.18). Upper and lower contacts of these units are generally subhorizontal. The upper unit is within the Karapiro Formation and the lower unit in the Whangamarino Formation.

Ignimbritic silts are generally identified on the basis of their halloysitic composition, textural uniformity (Figure 3.21) and extensive nature (pers. comm. C. Nelson, 1985). Two major layers of ignimbritic silts are recognised within the Tauranga Group sequence. The upper layer which generally follows relief over the hostel site is up to c.10m thick comprising the Kauroa-Hamilton Ashes. The lower layer is within the Whangamarino Formation, and is generally flat lying, ranging in thickness from 4 to 10 metres.

Three 'distal ignimbrite' deposits, including both sands and silts have been described in the Whangamarino Formation at Ohinewai (6km north of hostel site) by Todd (1982a). It is possible that the ignimbritic deposits within the Whangamarino Formation at the hostel site are lateral equivalents to those described by Todd. No ignimbritic deposits have been previously described from the Karapiro Formation. The upper most ignimbritic silt unit interpreted as comprising the Kauroa-Hamilton Ashes are regionally extensive over the Lower Waikato Basin (Ward, 1967).

B) Fluviatile deposits

Fluviatile deposits are identified on the basis of fine to coarse layering (bedding and lamination), the greywacke[1] component of material composition and association with peat and gravel (Figure 3.22). Texturally these deposits range from clayey silts to medium gravels and comprise the non-ignimbritic component of the Whangamarino, Karapiro and Hinuera Formations.

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1. "Greywacke" is used here as a field term and refers to the highly inurated sandstones and siltstones of the Newcastle Group.

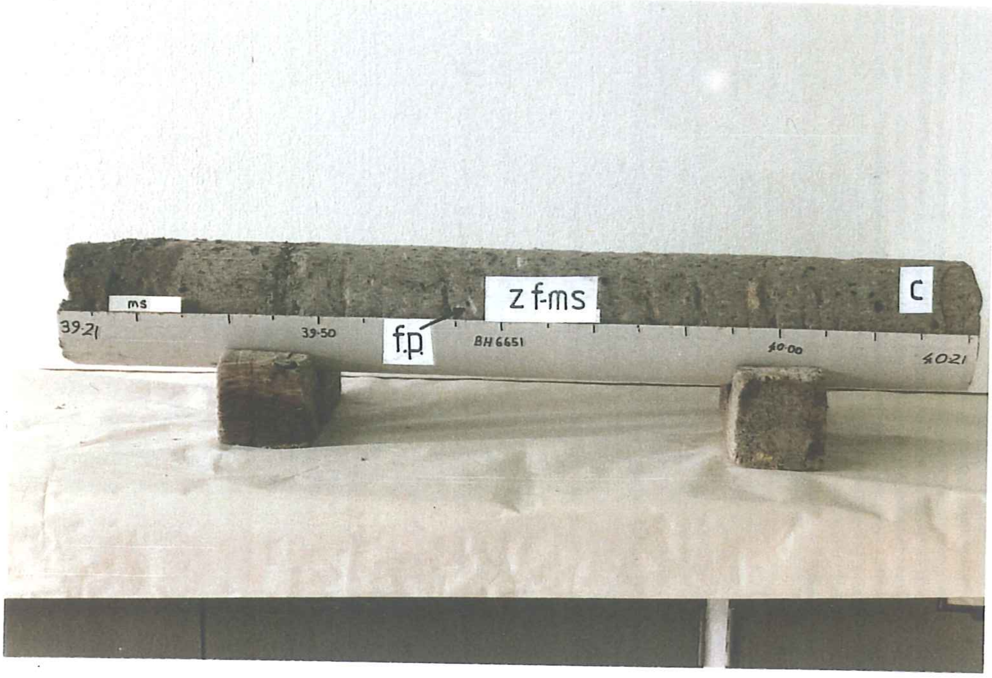

Figure 3.20: Upper part of a c.4m thick ignimbritic SILTY fine to medium SAND (SC), BH6651, Whangamarino Formation. Note the massive nature of the deposit, flattened pumice fragments (f.p.) and minor charcoal (c).

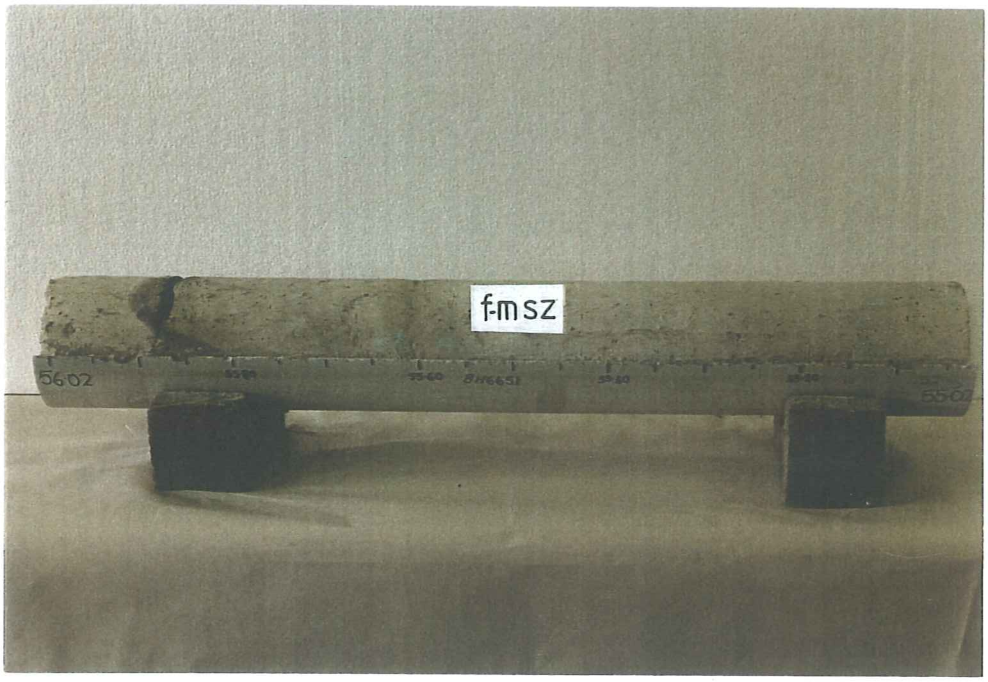

Figure 3.21: Part of a c.10m thick ignimbritic fine to medium SANDY SILT with some clay (ML), lower ignimbritic silt unit, BH6651, Whangamarino Formation. The outside of the cone has oxidised from the original light greyish green (seen in part) to the whitish yellow. Note the materials massive nature.

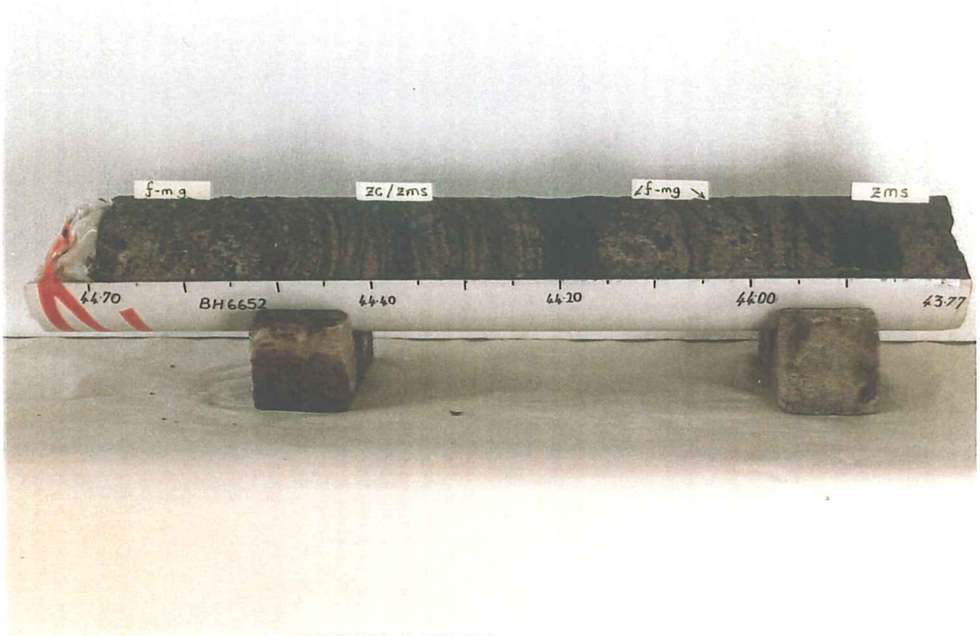

Figure 3.22: Fluvial interlayered sequence of fine to medium GRAVELS (GM), composed of reworked Tauranga Group and greywacke clasts, SILTY CLAY, SILTY medium SAND (SM) and wood fragments (at 44.20m), BH6651, Whangamarino Formation. Note the fine and coarse layering (bedding) controlling material variability.

Engineering geological descriptions of fluviatile materials are presented in Appedix Two . Bedding attitudes are variable within these materials and range from subhorizontal up to 10^{o}.

The fluviatile nature of materials within the Whangamarino, Karapiro and Hinuera Formations has been well documented regionally by Kear and Schofield (1978) and at Ohinewai by Todd (1982a).

C. Stratigraphic Correlations

The major stratigraphic units recognised within the succession are the Whangamarino Formation, Karapiro Formation and the Kauroa-Hamilton Ashes (Figures 3.17 and 3.18). The Waeranga Gravels (of greywacke composition) although recognised, are not described separately as they are interlayered and partially transitional with both the Whangamarino and Karapiro Formations.

1. Whangamarino Formation

Unconformably overlying the coal measures is a 20 to 35 metre thick sequence of light bluish-green, olive-white and olive-brown, interlayered ignimbritic sands and silts plus fluviatile silts, sands and gravels with rare peat. Intersected in boreholes 6651 to 6656 at the top of this sequence is a c. 0.2m thick highly to completely weathered, organic rich, dark brown clayey silt.

On the basis of colour and stratigraphic position this sequence is interpreted as being part of the Whangamarino Formation. The weathered silt which marks the upper boundary is interpreted as representing a paleosol.

This formation is extensive being described regionally by Kear and Schofield (1978), at Ohinewai by Todd (1982a) and over the north headings of Huntly East Mine by Todd (1982b).

2. Karapiro Formation

Overlying the paleosol at the top of the Whangamarino Formation is a 10 to 40 metre thick sequence of light and dark, grey and brownish yellow interlayered ignimbritic sands and fluviatile silts, sands, gravels with rare peat.

This succession is interpreted as being part of the Karapiro Formation on the basis of colour and stratigraphic position. As with the Whangamarino Formation this unit is extensive being described regionally by Kear and Schofield (1978), at Ohinewai by Todd (1982a), and over the north headings of Huntly East Mine by Todd (1982b).

3. Kauroa-Hamilton Ashes

Mantling the Karapiro Formation over the hostel site is a c.4 to 10 metre thick interlayered sequence of commonly mottled, light reddish-yellow and yellowish-brown ignimbritic silts with minor silty sands.

On the basis of colour, composition and stratigraphic position this sequence is interpreted as being part of the Kauroa-Hamilton Ashes described by Ward (1967). Ward reports 4-5 metres of Kauroa and Hamilton Ash at Huntly as part of his extensive study over the Lower Waikato Basin. Distinguishing between the ash formations is beyond the scope of this study.

4. Hinuera Formation

Overlying the Karapiro Formation and Kauroa-Hamilton Ashes and extensive under low lying areas north and west of the hostel area is an interlayered sequence of light yellowish brown and greyish green fluviatile silts, sands, gravels and peat.

On the basis of stratigraphic position and colour, this sequence in interpreted as being part of the Hinuera Formation. Due to compositional similarity with the underlying Karapiro Formation, the base of the Hinuera Formation is not easily recognised.

Kear and Schofield (1978) map the extensive flat area west of the hostel as an aggradation surface related to deposition of the Taupo Pumice Alluvium. The alluvium is not present in boreholes and was possibly largely removed with residential development.

3.8.4 Groundwater Hydrology

Combining the large scale cross-sections (Figures 3.17 and 3.18) with field (Section 3.5.2) and laboratory (Section 4.6) permeability data, the groundwater hydrology of the site can be described.

Three aquifers[1] are recognised within the Tauranga Group sequence. Described as the upper, middle and lower, aquifer permeabilities are estimated as ranging from 10^{-2} - 10^{-3} m/s for gravels (estimate from Terzaghi and Peck, 1967, p.55) to 10^{-5} - 10^{-7} m/s for sands. Aquifers are separated by two silt aquitards with estimated permeabilities of 10^{-7} - 10^{-10} m/s. The Waikato Coal Measures at the base of the Tauranga Group sequence with estimated permeabilities of 10^{-8} - 10^{-10} m/s (Table 1.2) represent an aquiclude. Localised zones within the coal measures have higher permeabilities due to the presence of joints and faults (B.M.C., 1984) or possibly mining induced fractures as suggested by the tentative engineering geological model in Figure 2.14.

Cross-section analysis (Figures 3.17 & 3.18) indicates that the lower aquifer is confined with the middle and upper aquifers laterally extensive and possibly unconfined. The lower and middle aquifers are within the Whangamarino Formation with the upper aquifer consisting of the Karapiro and Hinuera Formations.

Todd (1982b) in his groundwater study over the northern headings of the East Mine reports a similar sequence with two aquifers in the Whangamarino Formation and a third being represented by the Karapiro and Hinuera Formations. In two areas over the north headings Todd notes that the middle and upper aquifers are in direct contact. B.M.C. (1984), because of hydraulic continuity between the upper and middle aquifers describe the Tauranga Group in terms of two aquifer systems (Figure 3.23). The two aquifer systems are discussed in Section 1.5.4.

The phreatic surface of the upper aquifer at the hostel site based on S.C.M. monitoring data is present in Figure 3.24. The phreatic surface slopes to the north west over the hostel site and is horizontal (c. 2m deep) below

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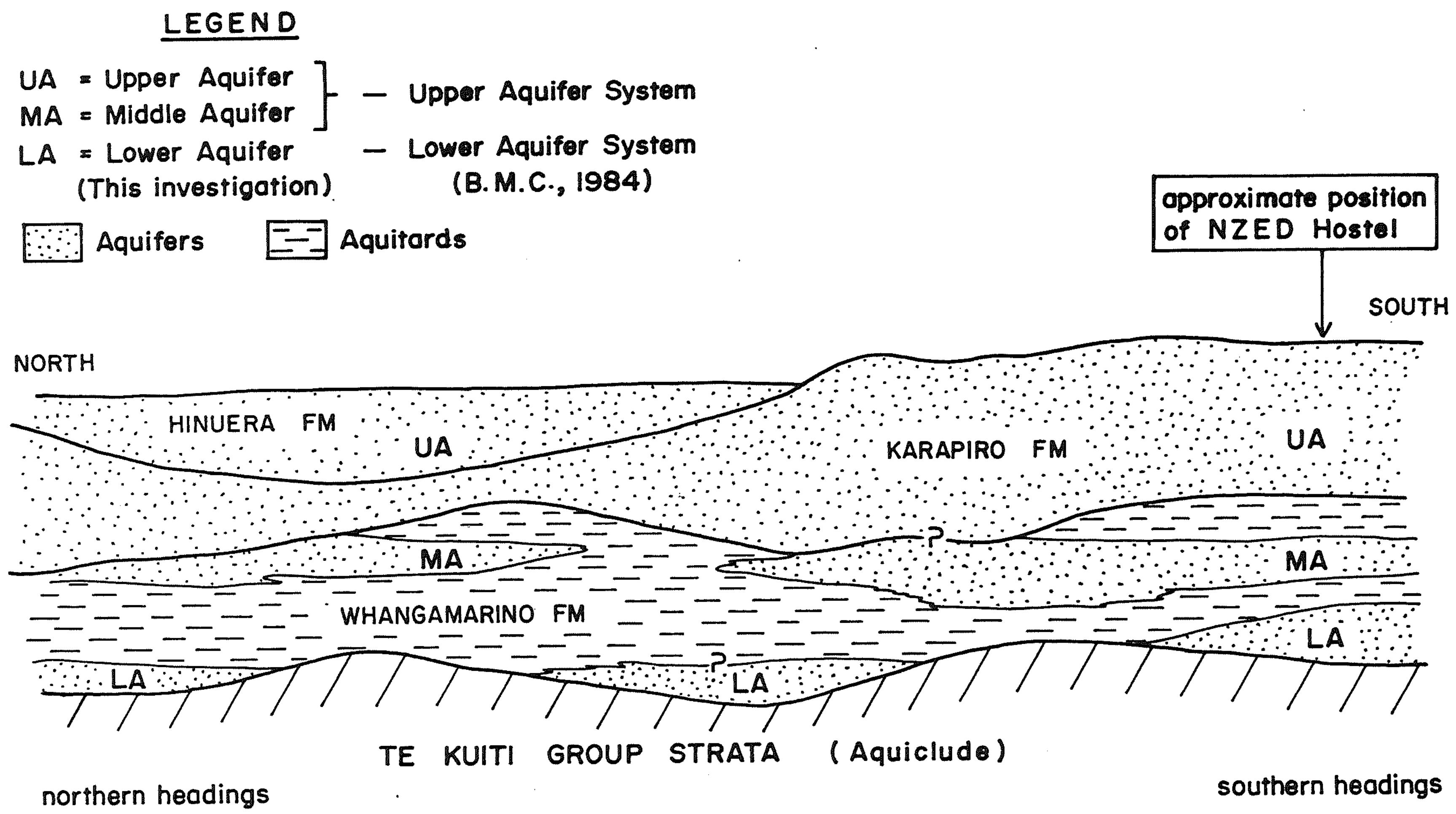
1. See Appendix One for definitions of hydrological terms.



Note: This diagram is not to scale

Figure 3·23: Schematic cross-section showing the general relationship between aquifers and aquitards in the Tauranga Group sequence over the northern and southern headings, Huntly East Mine

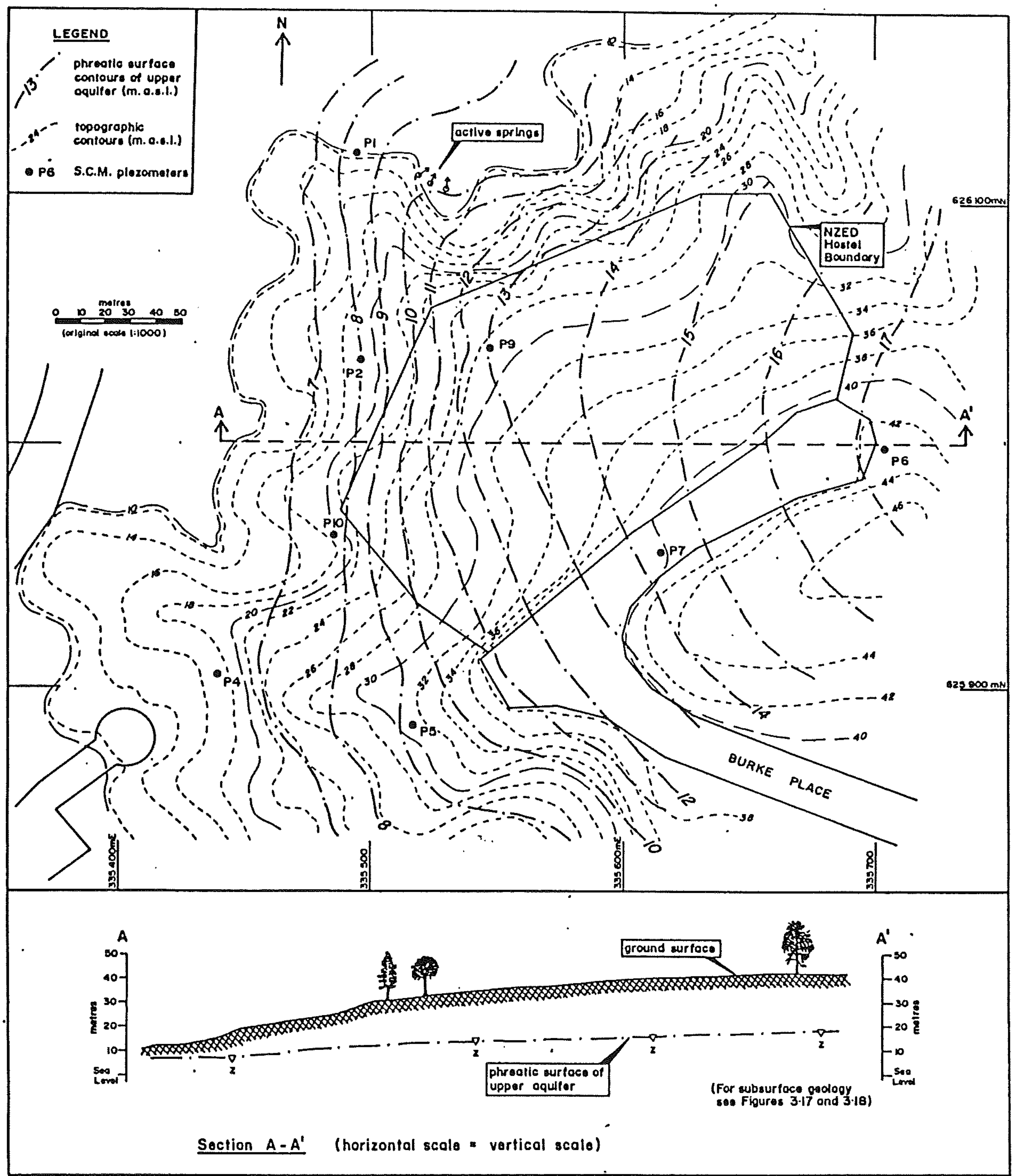


Figure 3·24: Phreatic surface of upper aquifer over hostel site. Constructed from average S.C.M. piezometer water levels over September, 1983.

the flat area of Rosser Street. Springs (Section 3.2.1) at the base of the slope below the hostel represent areas where the phreatic surface is in contact with the ground surface.

CHAPTER IV

LABORATORY INVESTIGATIONS

4.1 Laboratory Investigation Objectives and Approach

To augment field investigations, laboratory testing was conducted to further quantify the tentative engineering geological model (Figure 2.14) for geotechnical analysis (Chapter Five). Objectives of the laboratory investigations are:

1) to characterise materials in terms of their grain size distribution, clay mineralogy, density, void ratio and natural water content.

2) to determine material consolidation parameters.

3) to determine material permeabilities.

4) to study material fabric as it relates to soil compressibility.

The laboratory testing programme was generally restricted to samples from the fully cored borehole 6651, located in the maximum area of subsidence. Limited consolidation and material characterisation tests were completed on samples from borehole 6652 and 6653 located on the outer margins of the hostel subsidence trough. This approach allows the identification of any possible compressible units within the Tauranga Group sequence with respect to this subsidence area. Laboratory data is used in the back analysis procedures of Chapter Five to investigate the likely dewatering consolidation component of the hostel subsidence.

Laboratory testing has been undertaken by a number of investigators. All permeability, the majority of the consolidation and material characterisation tests were completed as part of this study. The remainder of the consolidation tests were carried out by the Hamilton District Laboratory of the M.W.D. (1985 a,b), with material characterisation testing being completed by Wezenberg (1985) under supervision of the author. All other data, including laboratory investigations (M.W.D., 1983) on core from M.W.D. borehole 6599 (see Section 2.4) is reviewed in this chapter.

4.2 Sample History

To minimise sample disturbance and changes of moisture content, core (150mm diameter) retrieved during drilling (Section 3.3) was initially placed in split p.v.c. garnite tubing, wrapped in plastic and stored under refrigeration. During transport from Huntly to Christchurch the wrapped core was supported by wet wood shavings and on arrival stored in a humidity room until testing. All materials apart from loose gravels and poorly graded fine sands arrived in Christchurch in an undisturbed condition. Selected samples of core were transported from Huntly to Christchurch. The remaining material from the drilling programme is stored at Huntly by S.C.M.

4.3 Material Characterisation

4.3.1 Test procedures and results

Laboratory procedures for grain size analyses, natural moisture contents and Atterberg Limits are in accordance with N.Z. Standards 4402, Part 1 (1980). Due to the suspected presence of allophane, samples used for Atterberg Limit determinations were maintained at or above their natural moisture contents. Determinations of void ratios, dry and bulk densities were made in conjunction with one-dimensional tests following procedures described in N.Z.S. 4402, Part 2P, Test 21 (1981). Clay mineralogy was determined using an X-ray Diffractometer (X.R.D.) and the sodium fluoride reactivity test (N.Z.S. 4402, Part 1, Test 13, 1980) for allophane content. Solid densities were determined using a technique especially designed for pumiceous materials, and originally developed by the M.O.W. (1958).

Classification tests completed on ignimbritic and fluviatile materials from boreholes 6651 and 6599 are presented in Tables 4.1 and 4.2. Envelopes representing ranges of grading curves for both material types are presented in Figures 4.1, a to c. Saturation ratios are presented with consolidation data in Tables 4.3 and 4.4.

4.3.2 Interpretation and Discussion

4.3.2.1 Void ratios, densities and moisture contents

The Tauranga Group sequence is generally characterised by high void ratios (average e is 1.37), low dry densities (average ρ_d is 1.01 t/m^3) and high moisture contents (average w is 53%) which are indicative of 'open' structured materials with a large component of void space.

The 'open' structured nature of deposits is interpreted as being due to:

1) the pumice component of the sand to fine gravel fraction within ignimbritic and fluvial materials.

2) the 'loose' packing of the silt fraction (Section 4.5) within ignimbritic materials.

3) the presence of allophane in the clay fraction (Section 4.3.2.4) within ignimbritic and fluvial materials.

Notable in terms of their 'open' texture are the ignimbritic sandy silts and silty sands with clay-silt contents of greater than 53% (BH6651, at 7.21m, 9.80m, 55.28m and 55.50m - Table 4.1) and whose void ratios range between 2.23 and 2.77. These values are contrasted by void ratios of the fluvialite clayey and sandy silts (BH6651, at 34.9m and 61.9m) which are measured at 0.84 and 0.77 respectively.

High void ratios combined with low dry densities and

TABLE 4.1: CLASSIFICATION TEST RESULTS FOR IGNIMBRITIC AND FLUVIATILE MATERIALS FROM BOREHOLE 6651

MATERIAL FIELD DESCRIPTION	Depth (m)	Moisture Content [1] (w %)	Dry Density [1] ρd (t/m³)	Solid Density ρs (t/m³)	Void Ratio [1] e	Particle size Analysis (%) c	z	s	g	Atterberg Limits (%) LL	PL	PI	CLAY MINERALOGY X-ray Diffraction	Allophane Test
Ignimbritic materials:														
Pumiceous SANDY SILT with some clay (K-H) (3)	7.21	91.0	0.83	2.66	2.23	7	48	45	- (2)	83	51	32 (2)	Halloysite (2)	c. 5-7% (2)
Pumiceous SILTY fine to medium SAND with some clay (K-H)	9.80	88.4	0.80	2.65	2.33	12	41	47	-	51	38	13	Halloysite (?) and unidentified mixed layer clay	c.5-7%
Pumiceous SILTY fine to medium SAND (Kp)	13.0	50.0	1.08	2.47	1.27	2	35	63	-	N.O. (4)			N.T. (4)	N.T.
Pumiceous fine to medium SAND with some silt (Kp)	19.30	46.0	1.12	2.48	1.22	-	15	85	-	N.O.			N.T.	N.T.
Pumiceous fine to medium SAND with some fine gravel and silt (Kp)	22.60	47.4	1.13	2.44	1.16	2	11	82	5	N.O.			N.T.	N.T.
Pumiceous SILTY fine to medium SAND with some clay (Wg)	40.20	61.3	0.97	2.52	1.59	6	29	63	2	N.O.			N.T.	N.T.
Pumiceous SILTY fine to coarse SAND with some fine gravel (Wg)	43.70	65.9	0.92	2.39	1.60	-	17	75	8	N.O.			N.T.	N.T.
Pumiceous SANDY SILT with some clay (Wg)	55.28	98.0	0.74	2.69	2.66	5	60	35	-	N.T.			Halloysite and kaolin	c.5-7%
Pumiceous SANDY SILT with some clay (Wg)	55.50	103.5	0.71	2.69	2.77	10	55	35	-	67	55	12	Halloysite and kaolin	c.5-7%
Pumiceous SILTY fine to medium sand (Wg)	59.00	70.5	0.89	2.55	1.85	2	35	63	-	N.O.			N.T.	N.T.
Fluviatile materials:														
Organic CLAYEY SILT with some sand (Wg)	34.9	32.0	1.42	2.62	0.84	35	39	26	-	43	21	22	Unidentified mixed layer clay (plus tridymite)	c. 5-7%
SANDY SILT with some clay fine gravel and wood fragments (Wg)	61.9	29.3	1.49	2.63	0.77	8	52	35	5	52	23	29	Unidentified mixed layer clay	c. 5-7%

1 Moisture contents, dry densities and initial void ratios determined in conjunction with one-dimensional consolidation testing.

2 Grainsize analysis, Atterberg Limits and Clay Mineralogy determinations as part of this study. Evaluations below the first row are by Wezenberg (1985). Note that Wezenberg's Atterberg Limits are determined on whole sample while values determined as part of this study are from the silt-clay fraction.

3 Abbreviations for stratigraphy: (K-H) = Kauroa-Hamilton Ashes
(Kp) = Karapiro Formation
(Wg) = Whangamarino Formation

4 Abbreviations: N.O. = not available
N.T. = not tested.

TABLE 4.2: CLASSIFICATION TEST RESULTS FOR IGNIMBRITIC AND FLUVIAL MATERIALS FROM BOREHOLE 6599 (from Stewart, 1983; Heu, 1983)

Material Field Description	Depth (m)	Moisture Content (w %)	Solid Density ρs (t/m^3)	Void Ratio e	Particle Size Analysis (%)		
					c+z	s	g
<u>Ignimbritic materials:</u>							
Pumiceous SILTY fine to coarse SAND with some clay and gravel (K-H)	1.24-3.04	42.7	2.71	1.16	20	75	5
Pumiceous SILTY fine to coarse SAND (K-H)	4.10-5.70	33.3	2.69	0.90	28	70	2
Pumiceous SILTY fine to medium SAND (Kp)	13.00-16.54	49.0	2.44	1.20	40	60	-
Pumiceous SILTY fine to medium SAND (Kp)	16.54-26.25	39.2	2.46	0.96	18	79	3
<u>Fluviatile materials:</u>							
Medium to coarse SANDY fine to medium GRAVEL with some silt (Kp)	5.70-6.58	36.4	2.70	0.98	11	34	55
Pumiceous SILTY medium to coarse SAND with some silt (Kp)	6.58-13.00	35.0	2.67	0.93	14	82	4
Medium to coarse SANDY fine to medium GRAVELS (Kp)	38.19-40.25	21.0	2.59	0.54	2	29	69
Pumiceous fine GRAVELLY medium to coarse SAND (Kp)	40.35-41.71	88.9	2.34	2.08	5	80	15
Fine to medium GRAVELLY medium to coarse SAND (Wg)	45.25-48.55	31.3	2.66	0.83	8	70	22
Pumiceous SILTY fine to medium SAND (Wg)	48.55-50.45	35.7	2.67	0.95	14	86	-
Medium to coarse SANDY fine to medium GRAVELS (Wg)	50.45-52.00	26.9	2.62	0.70	2	43	55

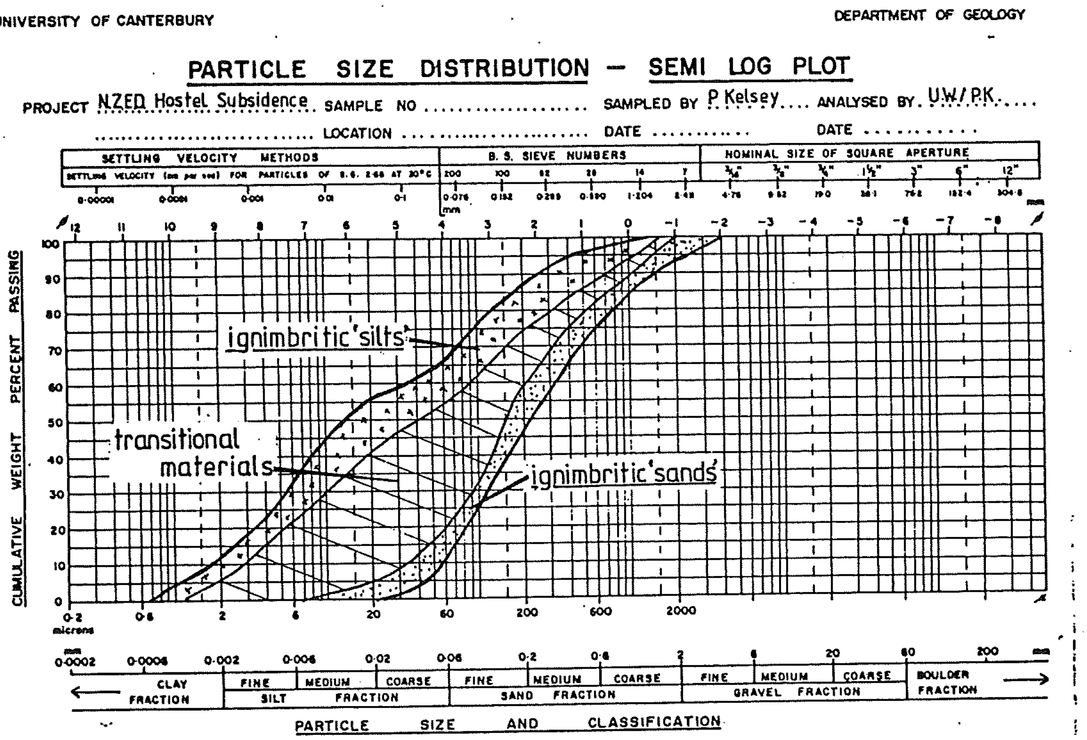


Figure 4.1a: Range of particle grading curves for ignimbritic materials.

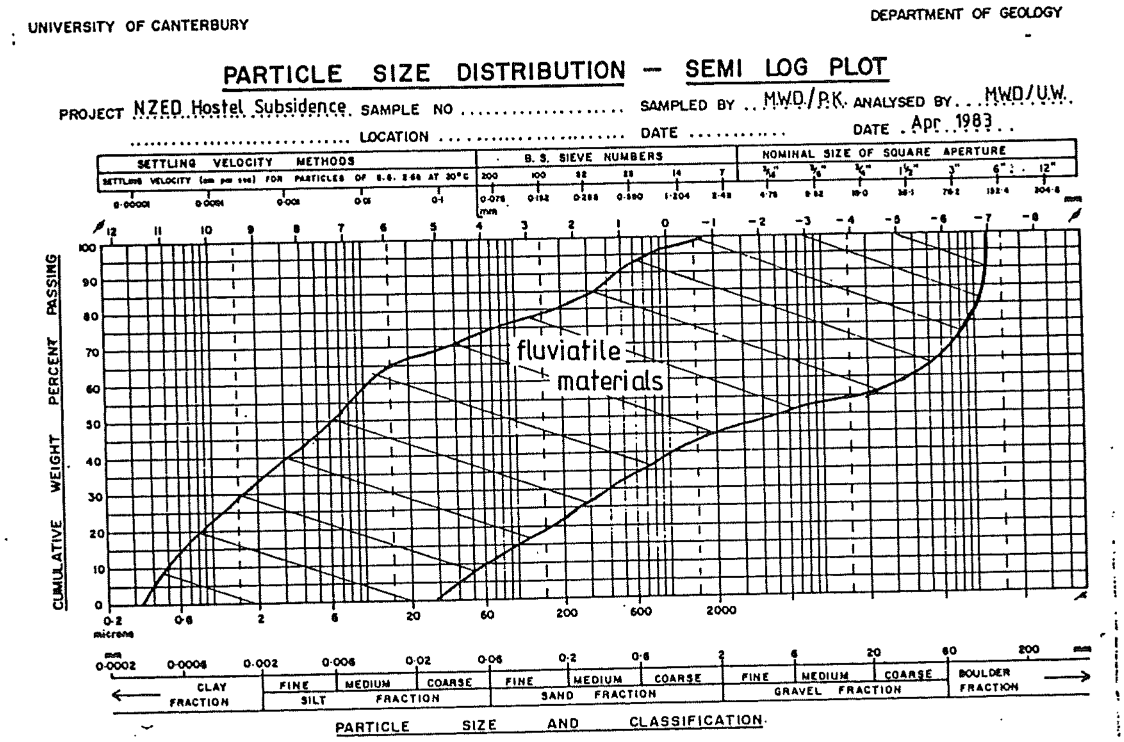


Figure 4.1b: Range of particle grading curves for fluviatile materials.

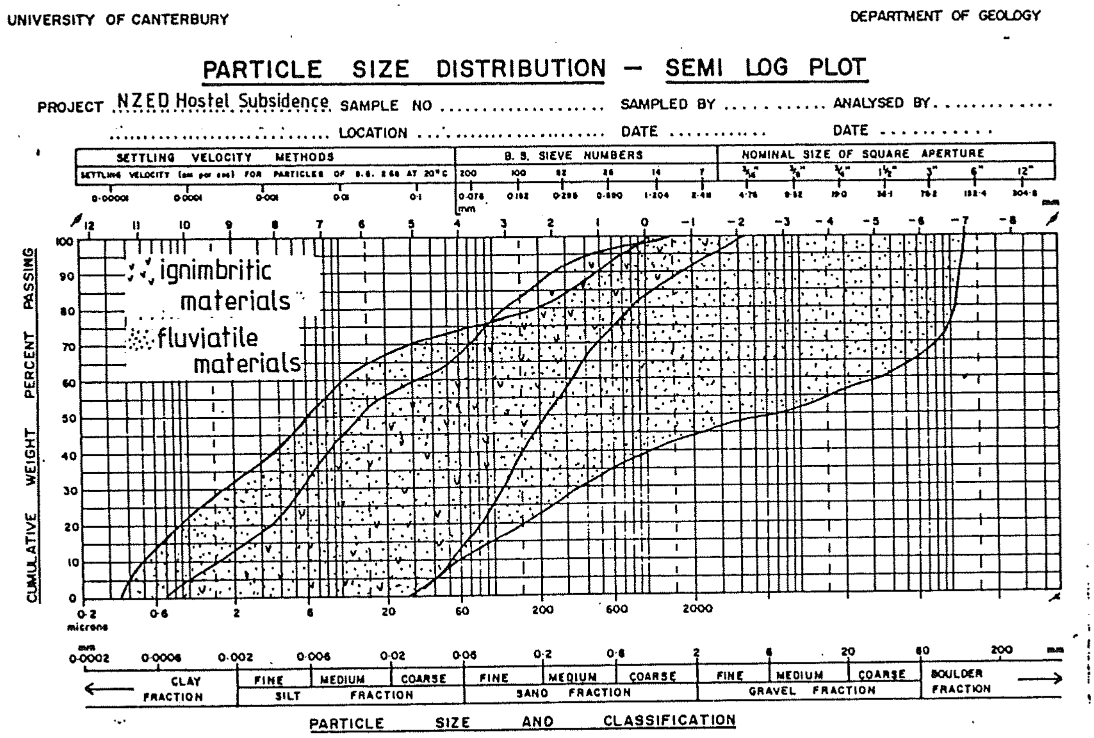


Figure 4.1c: Comparison of particle grading curves from ignimbritic and fluviatile materials.

high water contents are typical of ignimbritic soil materials (Prebble, 1983; Northey, 1966). Parton and Olsen (1980) in their study of Bay of Plenty volcanic soils measure void ratios of up to 5 with natural moisture contents in excess of 150%.

4.3.2.2 Particle size distributions

Particle size distribution curves (Figure 4.1 a,b) show the well graded nature of the ignimbritic and fluvial deposits, and that fines within the whole sequence are generally dominated by silt size particles. Grain size envelopes for both material categories (Figure 4.1 c) have a large 'area' of overlap which, together with their pumiceous content (Table 4.2) indicates that the fluviatile materials are in part the reworked (by river action) equivalents of the ignimbritic deposits.

4.3.2.3 Atterberg Limits

Ignimbritic sandy silts and silty sands are MH (Unified Soil Classification System) type materials with high plasticity, and fluviatile clayey and sandy silts CL and CH type soils with low to high plasticity.

It is generally accepted that soil materials with liquid limits greater than 50% exhibit high compressibility (Terzaghi and Peck, 1967; White, 1982). This relationship suggests that the ignimbritic silts (LL = 83% and 67% for BH 6651, at 7.21m and 55.50m) are highly compressible in comparison to the fluviatile silts (LL = 43% and 52% for BH 6651, at 34.9m and 61.9m). High liquid limits are commonly associated with allophanic soils (see Section 4.3.2.4) as described by Gradwell and Birrell (1954) in their study on the physical properties of volcanic clays.

4.3.2.4 Clay mineralogy

Allophane is common to all fine grained materials tested in the Tauranga Group sequence. Within all ignimbritic silt rich materials halloysite is identified and is associated with kaolin at depth (BH6651, 55.28m and 55.50m - Table 4.1). Within the fluviatile fine grained materials the allophane is present with an unidentified mixed layer clay. The possible mineralogies of the mixed layer clay as suggested by Wezenberg (1985) are either kaolin-smectite, or halloysite-vermiculite, or smectite-illite.

Studies of allophane (Henmi and Wada, 1976) have shown that the mineral consists of irregular aggregates of hollow, spherical shaped particles. The walls of the irregular spheres are radially partitioned forming 'tunnel-like' pores which allow the passage of water (Lowe and Nelson, 1983). As a result of this 'open' and 'bulky' structure, allophanic soils commonly have high natural water contents and low dry densities (Oborn et al., 1982). These properties are observed particularly within the ignimbritic silt rich units of the Tauranga Group succession (Section 4.3.2.1).

Allophane, halloysite and kaolin are common components of weathered volcanic materials in New Zealand (Gradwell and Birrell, 1954; Prebble, 1983).

4.4 Consolidation Testing

4.4.1 Consolidation parameters

When a load is applied to a saturated sample, it is initially supported by the incompressible pore fluid. The resulting increase in pore pressure is called hydrostatic excess pressure. With time the excess pore pressure dissipates as the water drains from the sample, with the load being gradually transferred to the compressible soil skeleton. Drainage and accompanying dissipation of excess pore pressure is controlled by the soils permeability. The transfer of load accompanied by a reduction in the soil mass volume (equal to the volume of water drained) is known in soil mechanics as consolidation (Terzaghi, 1925).

The conventional approach of characterising the rate of consolidation from the oedometer tests (Section 4.4.2) is shown in Figure 4.2. This figure plots the relationship

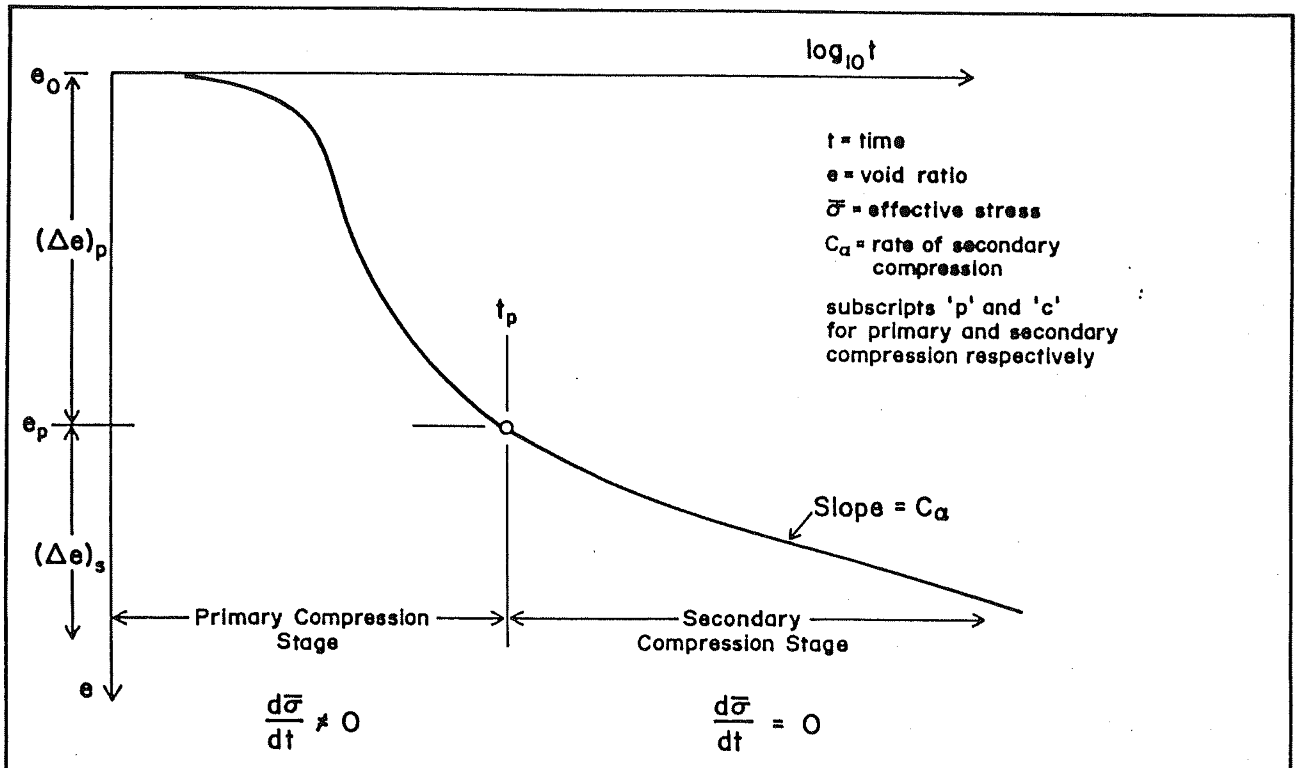


Figure 4·2: Definition of Primary and Secondary Compression Stages (adapted from Mesri, 1985).

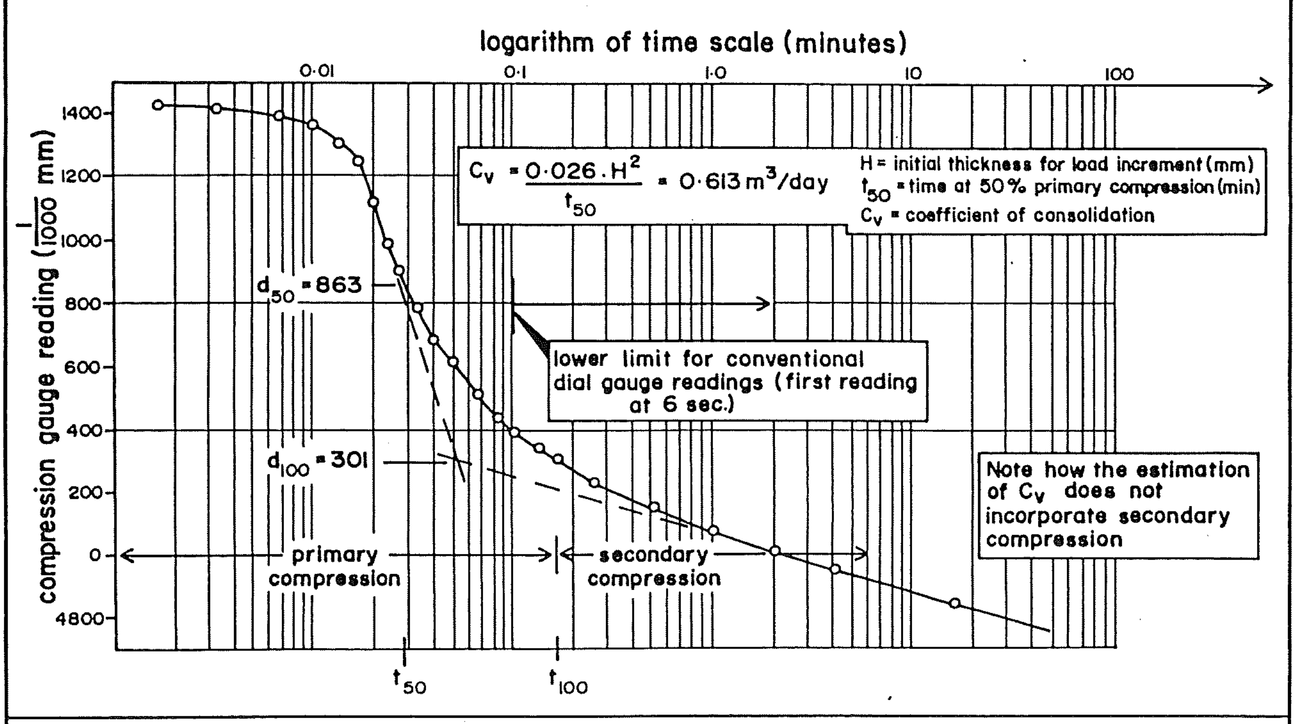


Figure 4·3: Estimation of C_v for the 1600 k Pa load increment on a sample from the upper ignimbritic silt unit (BH 6651, 6·50 m) using the empirical logarithm of time fitting method (Taylor, 1948).

between reduction in soil mass volume (expressed as a decrease in void ratio) with time for one load increment. Compression can be divided into two stages (Crawford, 1965):

1) primary compression that occurs while the excess pore pressure dissipates $\left(\frac{d\bar{\sigma}}{dt} \neq 0\right)$

2) secondary compression that occurs after excess pore pressure has dissipated $\left(\frac{d\bar{\sigma}}{dt} = 0\right)$

The coefficient of consolidation (c_v), commonly used to calculate settlement rates is evaluated for the same curve using the logarithm of time fitting method of Taylor (1948) shown in Figure 4.3. An equation is then used to evaluate c_v. Where secondary compression is highly developed c_v can be determined (for example Figure 4.3) but cannot be used for accurate predictions of the rate or final magnitude of settlement (Lambe and Whitman, 1979).

Secondary compression has a characteristic linear e-log t relationship with a slope represented by $C\alpha$ (rate of secondary compression).

The conventional approach of relating volumetric changes of the sample with increasing load is by plotting an e-log $\bar{\sigma}$ curve as shown in Figure 4.4. Estimations of the preconsolidation pressure ($\bar{\sigma}_c$), which indicates the past maximum effective stress, and compression index (C_c), which measures material compressibility can be made from the e-log $\bar{\sigma}$ plot. The coefficient of compressibility (a_v) is evaluated from plots of void ratio versus effective stress.

4.4.2 Test procedure and results

One-dimensional consolidation tests were performed in Casagrande oedometers on selected samples from BH6651, 6652 and 6653. Testing priority was given to the ignimbritic materials with high void ratios (Section 4.3.2.1). Test apparatus is shown in Figures 4.5 and 4.6. Procedures for the consolidation testing are in accordance with N.Z.S. 4402, Part 2P, Test 21 (1981). All consolidation testing apart from that carried out by M.W.D. (1985a,b), was

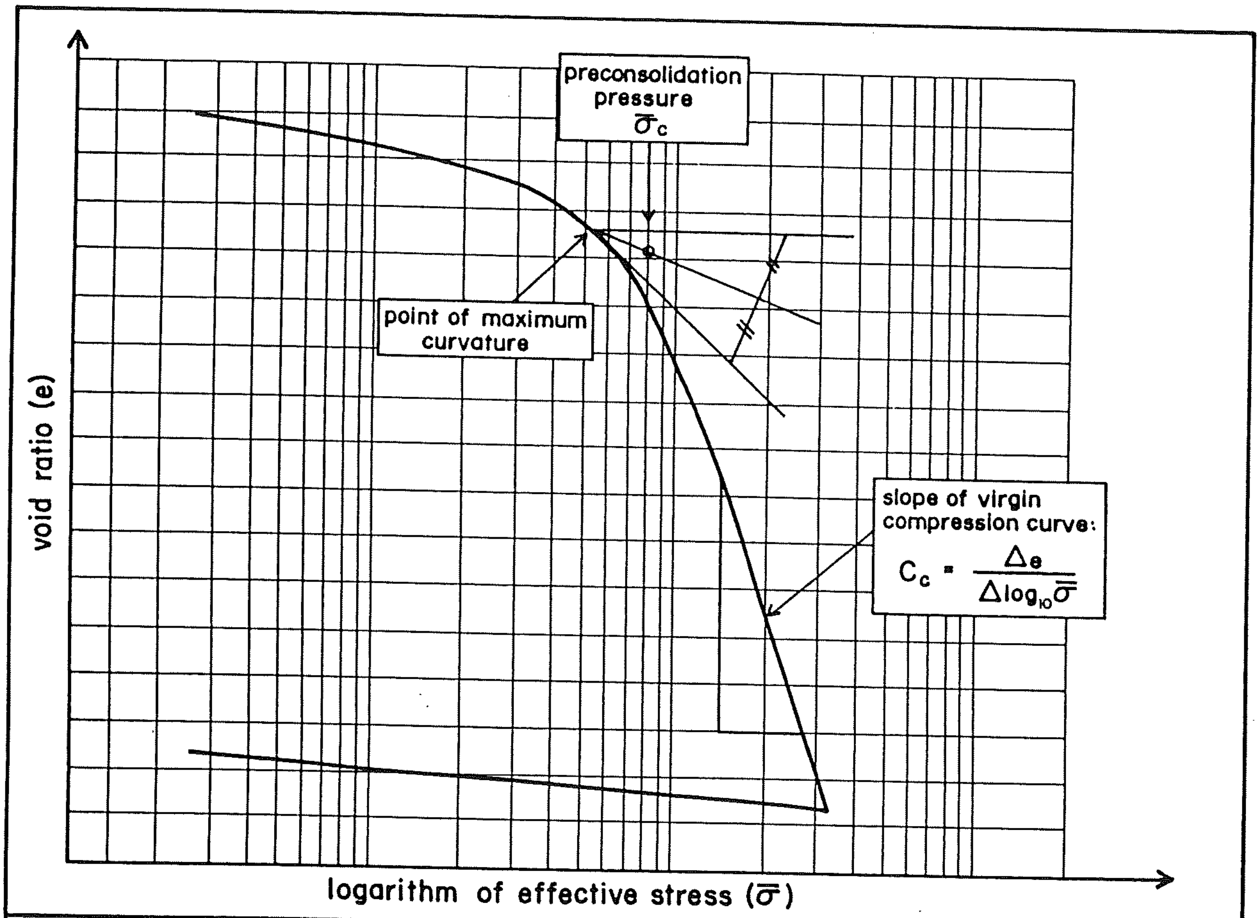


Figure 4·4 : Estimation of Compression Index (C_c) and Preconsolidation Pressure ($\bar{\sigma}_c$) from e - log $\bar{\sigma}$ plot (after Casagrande, 1936; Lambe and Whitman, 1979)

Figure 4.5: One-dimensional consolidation test apparatus. The load is applied by calibrated weights (painted green) through a lever arm to the oedometer cell (c) which contains the sample. Axial strain is measured by a dial gauge (accurate to 0.001mm).

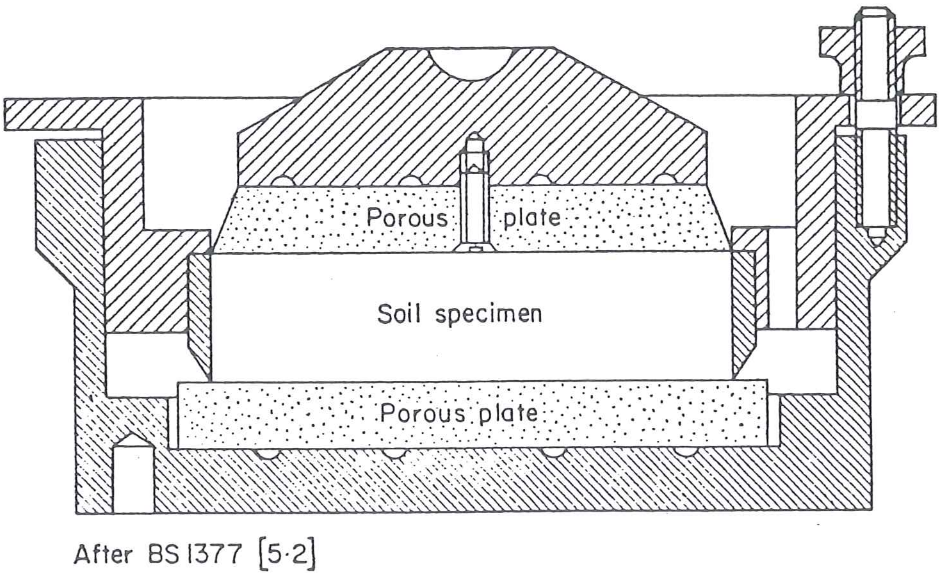


Figure 4.6: A section through a typical oedometer cell (from Scott [1980]).

completed in the Geomechanics Laboratory, Department of Civil Engineering, University of Canterbury.

Samples (76mm diameter x 19mm thick) were trimmed into the oedometer rings at their 'natural' moisture content from the 150mm diameter core. No difficulties were experienced during sample preparation. For the majority of tests, loads were applied every 24 hours, each test taking 8 days to complete. To investigate the duration of secondary compression, loads on 3 ignimbritic silt samples were applied every 7 days, the tests taking 50 days to complete. Loading for shallow samples in the Tauranga Group sequence ranged from 25 to 1600 kPa and for deeper samples 25 to 3200 kPa. All six oedometers used were calibrated for machine strain prior to operation.

Test results in terms of the consolidation parameters described in Section 4.4.1 plus the initial and final soil properties are presented in Table 4.3 and 4.4. Consolidation work sheets and plots of the e-log $\bar{\sigma}$ relationship for each sample are presented in Appendix 5.

The standard graphical precedures of estimating c_v (Section 4.4.1) within the ignimbritic silt rich materials were unsuccessful due to high material permeability causing primary compression to be complete before the initial 6 second dial gauge reading. Using a L.V.D.T. (Linearised Voltage Displacement Transducer) and a chart recorder which provided a continuous record of axial strain with time, c_v was able to be evaluated. A graph of axial deflection versus the logarithm of time using this procedure is shown in Figure 4.3. This figure shows that for the 1600 kPa load increment, primary compression is complete after c.3 seconds and that secondary compression is highly developed. A high degree of secondary compression is observed for all ignimbritic silt rich materials during the oedometer tests.

4.4.3 Interpretation and discussion

The test results show that the ignimbritic silts are highly compressible (C_c = 0.76 to 1.63 - Table 4.5) once their preconsolidation pressures ($\bar{\sigma}_c$) are exceeded. In terms of virgin compression indexes, least compressible within the

TABLE 4.3: CONSOLIDATION TEST RESULTS FOR BOREHOLE 6651

		INITIAL PROPERTIES					TEST RESULTS			FINAL PROPERTIES			
MATERIAL DESCRIPTION	* Sample Orientation	Depth (m)	Water Content (w %)	Dry Density ρd (t/m^3)	Void Ratio e	Degree of Saturation Sr (%)	Compression Index C_c	Preconsolidation Pressure $\bar{\sigma}_c$(k Pa)	Coefficient of Compressibility a_v (k Pa^{-1})	Water Content (w %)	Dry Density ρd (t/m^3)	Void Ratio e	Degree of Saturation Sr (%)
Ignimbritic SANDY SILT with minor clay (K-H)#	h	6.08	86.9	0.77	2.59	92.3	1.24	245		56.2	1.11	1.47	100
" "	h	6.45	79.3	0.85	2.56	97.0	0.97	365		55.6	1.12	1.46	100
" "	v	6.68+	78.9	0.87	2.15	100	0.91+	360+		56.8	1.10	1.49	100
" "	h	7.21	91.0	0.83	2.23	100	1.01	330		57.0	1.11	1.39	100
Ignimbritic SILTY fine to medium SAND with some clay (K-H)	h	9.83+	88.4	0.795	2.33	100	1.40+	210+		51.0	1.18	1.25	100
" "	h	10.50+	77.0	0.855	2.03	98.3	0.87+	180+		47.7	1.21	1.14	100
Ignimbritic SILTY FINE to medium SAND (Kp)	h	12.85	50.0	1.08	1.27	97.0	0.21	670		48.0	1.14	1.17	100
" "	h	13.59	49.4	1.09	1.22	98.0	0.16	680		47.7	1.14	1.13	100
Ignimbritic fine to medium SAND (Kp)	h	19.30	46.0	1.12	1.22	94.0	0.13	660	6.29×10^{-5}	46.0	1.17	1.11	100
" "	v	22.55	47.4	1.13	1.16	99.4	0.36	2120		46.0	1.20	1.03	100
Ignimbritic SANDY SILT (Kp)	h	27.85	89.5	0.75	2.25	97.5	1.15	975		73.6	0.88	1.77	100
Ignimbritic medium to coarse SAND (Kp)	h	28.65	75.8	0.81	2.03	91.7	0.83	990	2.05×10^{-4}	61.8	1.00	1.46	100
Fluviatile CLAYEY SILT with some sand (Wg) (Paleosol)	h	34.90	32.0	1.42	0.84	99.6	0.35	1290	5.50×10^{-5}	28.9	1.53	0.72	100
Ignimbritic SILTY fine to medium SAND with some fine gravel (Wg)	h	40.10	61.3	0.97	1.59	97.2	1.04	1370	7.25×10^{-5}	50.6	1.18	1.14	100
" "	h	43.70	65.9	0.92	1.60	98.2	0.76	2300		65.7	0.99	1.40	100
Ignimbritic SANDY SILT with some clay (Wg)§	h	51.0§	76§	0.88§	2.07§	100§	1.14§	1380§		64§	1.02§	1.66§	100§
" "	h	55.28	98.0	0.74	2.66	99	1.63	605		64	1.03	1.62	100
" "	v	55.40	103.5	0.71	2.77	100	1.60	530		78.4	0.89	2.01	100
" "	v	55.92	101.4	0.72	2.75	99	1.62	500		66.2	1.04	1.58	100
Ignimbritic SILTY fine to medium SAND (Wg)	h	58.89	70.5	0.89	1.85	97	0.97	795		48.6	1.15	1.20	100
" "	v	58.95	62.7	0.96	1.66	96.5	0.76	965		49.1	1.16	1.21	100
Fluviatile SILTY fine to medium SAND (Wg)	h	60.95	77.0	0.85	1.91	99.1	1.59	1920		64.0	0.97	1.53	100
Fluviatile SANDY SILT with some clay (Wg)	h	61.85	29.3	1.49	0.77	100	0.44	1390	3.0×10^{-5}	26.7	1.59	0.66	100
SILTY CLAY (weathered Waikato Coal Measures Mudstone)	h	66.30	24.0	1.66	0.58	100	0.18	1130		21.0	1.75	0.50	100

* Horizontal and vertical orientations of the flat circular surfaces of the cylindrical samples with respect to the Tauranga Group sequence.

\+ Tests carried out with one week loading cycles.

\# Stratigraphic abbreviations: (K-H) = Kauroa-Hamilton Ashes; (Kp) = Karapiro Formation; (Wg) = Whangamarino Formation

§ Consolidation tests by the Hamilton District Laboratories, M.W.D.

TABLE 4.4: CONSOLIDATION TEST RESULTS FOR BOREHOLES 6652 AND 6653

			INITIAL PROPERTIES				TEST RESULTS			FINAL PROPERTIES			
MATERIAL DESCRIPTION	Sample Orientation *	Depth (m)	Water Content (w %)	Dry Density ρd (t/m^3)	Void Ratio e	Degree of Saturation Sr(%)	Compression Index C_c	Preconsolidation Pressure $\bar{\sigma}_c$(k Pa)	Coefficient of Compressibility a_v ($k\ Pa^{-1}$)	Water Content (w %)	Dry Density ρd (t/m^{-3})	Void Ratio e	Degree of Saturation Sr (%)
BH 6652													
Fluviatile SANDY SILT with some clay (Wg)#	h	39.50	26.1	1.55	0.70	98.5	0.10	1230		26.6	1.56	0.69	100
BH6653													
Fluviatile SILTY fine SAND (Kp)	v	16.05	51.9	1.06	1.26	98.3	0.096	480		51.7	1.09	1.18	100
BH6653 - MWD (1985a,b)													
Fluviatile medium to coarse SAND with some fine gravel (Kp)	h		94	0.67	2.67	86	1.11	1080		73	0.86	1.84	96
" " " " "	h	18.31-19.31	43	1.13	1.16	90	0.49	1280		40	1.27	0.93	100
" " " " "	h	"	42	1.17	1.09	94	0.392	1280		39	1.31	0.86	100
Ignimbritic CLAYEY SILT with some sand (Wg)	h	47.00	93	0.77	2.54	100	1.63	1000		68	0.98	1.79	100
" " " " "	h	48.00	95	0.76	2.61	100	1.69	980		67	0.99	1.78	100

* Horizontal and vertical orientations of the flat circular surfaces of the cylindrical samples with respect to the Tauranga Group sequence.

Stratigraphic abbreviations: (K-H) = Kauroa-Hamilton Ashes
(Kp) = Karapiro Formation
(Wg) = Whangamarino Formation

TABLE 4.5: A SUMMARY OF VIRGIN COMPRESSION INDEX (C_c) DATA, TAURANGA GROUP SEQUENCE.

Material Type	Range of C_c	Average C_c
Ignimbritic silts (silt and clay fraction >53%)	0.76-1.63	1.18 (15)*
Ignimbritic sands	0.13-1.04	0.50 (7)
Fluviatile silts	0.10-0.44	0.30 (3)
Fluviatile sands	0.39-1.59	0.89 (4)

* number of one-dimensional consolidation tests completed for each material type.

sequence are the fluviatile silts (C_c = 0.10 to 0.44) followed by the ignimbritic (C_c = 0.13 to 1.04) and fluviatile (C_c = 0.39 to 1.59) sands (Table 4.5). The large ranges of C_c values observed for the ignimbritic and fluviatile sands are interpreted as being due to variations in silt content, interparticle packing and the percentage of pumice within the sample. Pumiceous sands are considered more prone to granular breakdown during consolidation testing than quartz-feldspar rich sands.

The preconsolidation pressure ($\bar{\sigma}c$) for each sample is estimated from the e-log$\bar{\sigma}$ plots (Figure 4.4; Appendix 5) using the graphical procedure of Casagrande (1936). For samples from the fully cored borehole 6651, estimated values of $\bar{\sigma}c$ are plotted with calculated overburden effective stresses in Figure 4.7. As this figure shows materials within the sequence range from normally consolidated to highly overconsolidated.

Significant in terms of determining the cause of overconsolidation within the sequence is the reduction in measured σc with depth between 6.45m and 9.83m, 43.70m and 55.10m, plus 60.95m and 61.85m. These trends combined with the general slightly overconsolidated nature of the ignimbritic silts from 48.00m to 58.00m suggest that the majority of the overconsolidation is 'apparent' rather than due to past greater overburden stress. Possible causes of the 'apparent' overconsolidation are:

1) dessication within the upper 10 metres of the sequence where negative pore pressure in the capillary zone increases the effective stress causing the soil to consolidate.

2) partial welding within the ignimbritic sand deposits during emplacement.

3) iron cementation from groundwater (observed in core at 43.70m where σc = 2300 kPa).

No significant differences in preconsolidation pressures from the lower ignimbritic silt unit are observed

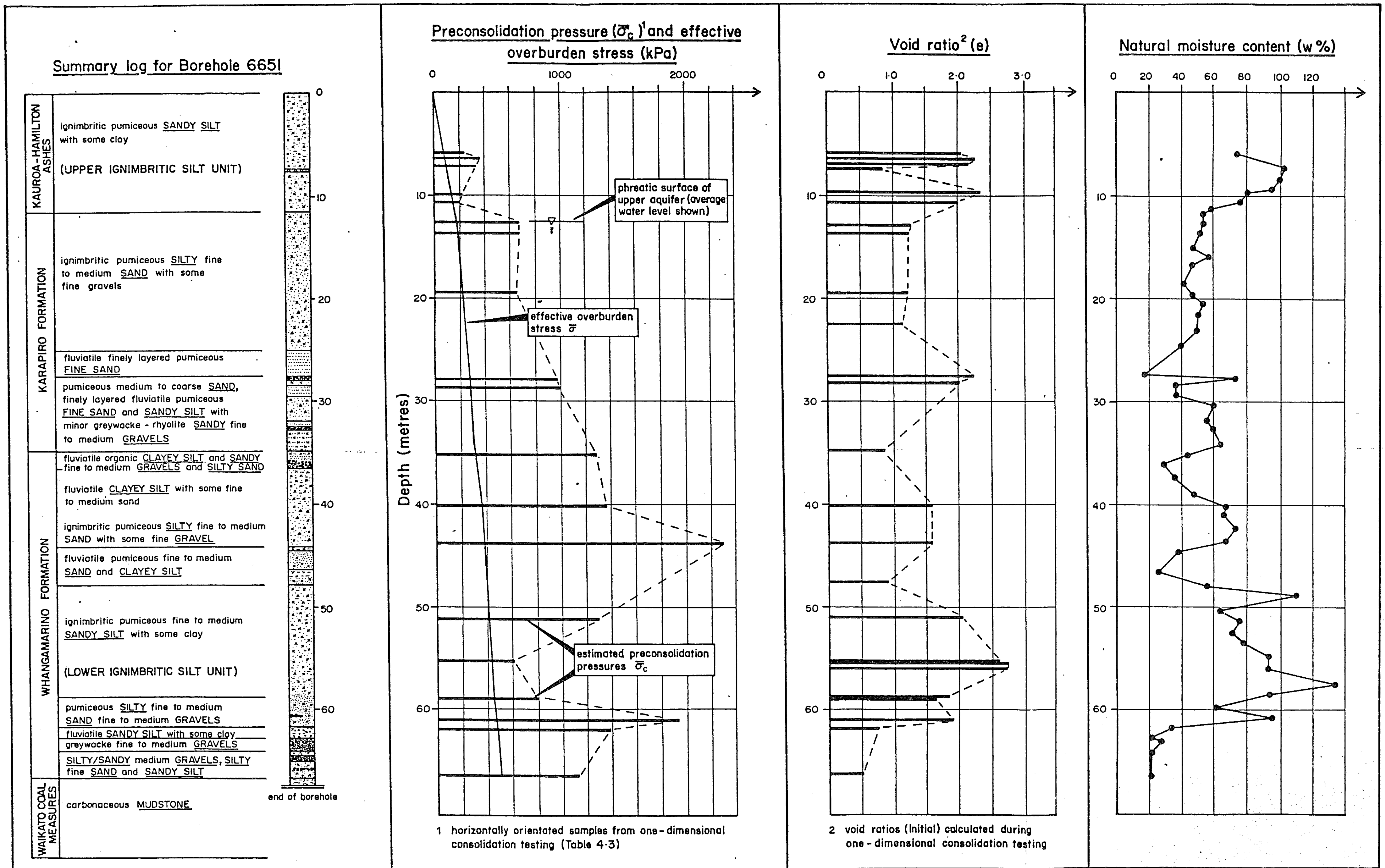


Figure 4·7: Consolidation, void ratio and natural moisture content data for Borehole 6651

Fig. 4·7

between samples central to the subsidence area (BH6651, samples at 51.0m to 58.95m) and those from the outer margins of the subsidence trough (BH 6653, samples at 47.00m and 48.00m).

Vertically and horizontally orientated samples (orientation of the upper and lower surfaces of the cylindrical sample used in the oedometer with respect to the Tauranga Group sequence) of ignimbritic materials generally have similar vlaues of C_c (Table 4.3) which suggests isotropic compressibility within the sequence. This isotropy is consistent with the massive nature of the deposits observed during field description and S.E.M. studies (Section 4.5). Values of $\overline{\sigma}_c$ are also similar apart from samples at 19.30m (horz.) and 22.55m (vert.) from BH 6651 where a difference of 1,460 kPa is recorded. Similar values of $\overline{\sigma}_c$ suggest that the effects of 'apparent' overconsolidation are generally equal in both horizontal and vertical directions. Observations of Fe-oxide banding in core (Appendix 2) is interpreted as causing the very high $\overline{\sigma}_c$ value at 22.55m.

Estimations of c_v were not made from the oedometer test data because of the well developed secondary compression observed within the highly compressible ignimbritic silts (discussion of the effects of secondary compression on c_v is presented in Section 4.4.1). For a typical 24 hour load increment primary and secondary compression comprised 60% and 40% respectively of the overall axial strain. Three oedometer tests were completed on ignimbritic silt materials (BH6651, samples at 6.68m, 9.83m, and 10.50m) with 7 day load increments. At the end of each load cycle for all three samples, secondary compression with its characteristic linear e-log t relationship (Figure 4.2) was observed. The alternative procedure for calculating settlement rates uses a_v with measured values of k which is adopted for analysis in Chapter Five. The rapid completion of the primary compression phase after loading (Figure 4.3) for the ignimbritic silts is interpreted as being due to relatively high material permeability (c. 10^{-7}m/s, Section 4.6).

To date the highly compressible ignimbritic silts have not been identified from investigaions in the Huntly area by S.C.M. (pers. comm. D. Depledge, Senior Mining Engineer, 1985), at Ohinewai by R.W.L. Mining Consultants (R.W.L., 1984) or in the Waikato area by M.W.D. (pers. comm. R.L. Williams, M.W.D. Senior Civil Engineer, 1985). However, investigators of the Taranaki ash deposits (Gradwell and Birrell, 1954; White, 1982; Fullarton, 1978) describe the volcanic clayey silts to silty sands as highly compressible with typical void ratios of 3 to 6 and C_c values ranging form 1 to 2.

4.5 Fabric Study

4.5.1 Introduction

Fabric studies are undertaken to investigate the ignimbritic silt materials in terms of their high void ratios (Section 4.3.2.1) and reponse to consolidation testing. The two samples investigated (BH6651, 9.84m and 55.28m) are from the main upper and lower highly compressible ignimbritic silt units described within the Tauranga Group sequence.

4.5.2 Method and Results

Soil fabric observations were made using the D.S.I.R. Scanning Electron Microscope (S.E.M.) operated in the Plant and Microbiological Sciences Department, University of Canterbury.

Sample preparation involved oven drying (oven temperatures 105^o - 110^oC), mounting on S.E.M. stubs and application of a thin coating (200 Å - 500 Å) of gold-palladium. Samples were stored in a dessicator before use in the S.E.M.

The S.E.M. produces an enlarged, three-dimensional view of the sample surface. Selected S.E.M. micrographs from both samples before and after consolidation testing are shown on Figures 4.8 to 4.12. The micrographs were taken in stereoscopic pairs for the fabric study.

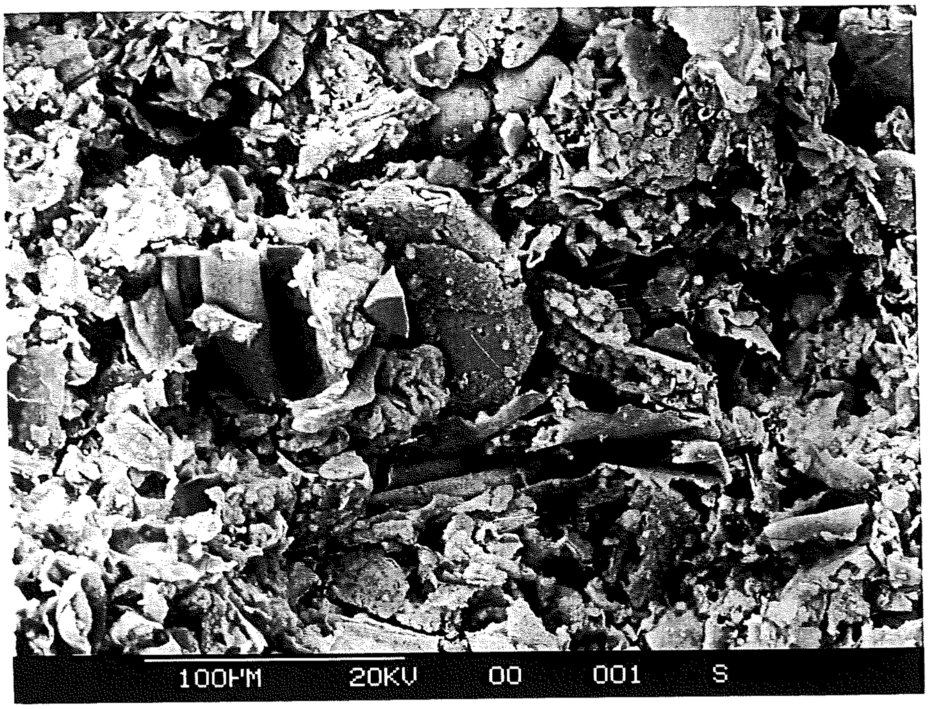


Figure 4.8: S.E.M. micrograph of an ignimbritic fine to medium SANDY SILT with some clay (BH 6651, 9.84m - upper ignimbritic silt unit) before consolidation testing. Note the 'open' fabric and the platy, nodular and tabular forms of halloysite. Void ratio = 2.33.

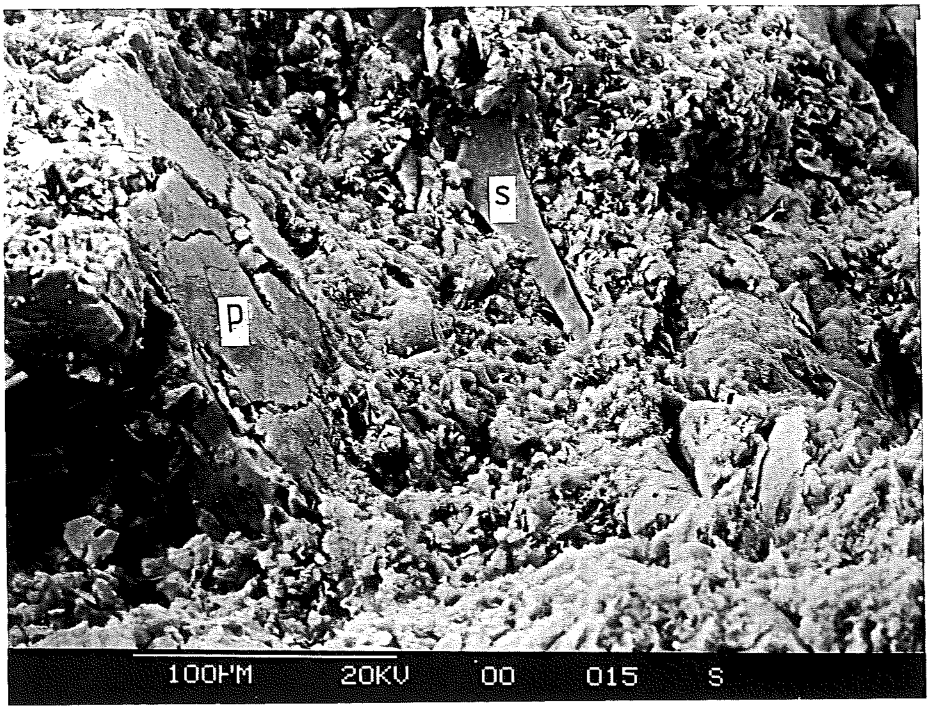


Figure 4.9: S.E.M. micrograph of the ignimbritic SANDY SILT shown in Figure 4.8, but after consolidation testing. The micrograph is at the same scale as Figure 4.8 and exhibits a more compact arrangement and general fragmentation of the matrix. Note the fractured pumice sand grain (p) and the glass shard(s). Void ratio = 1.25.

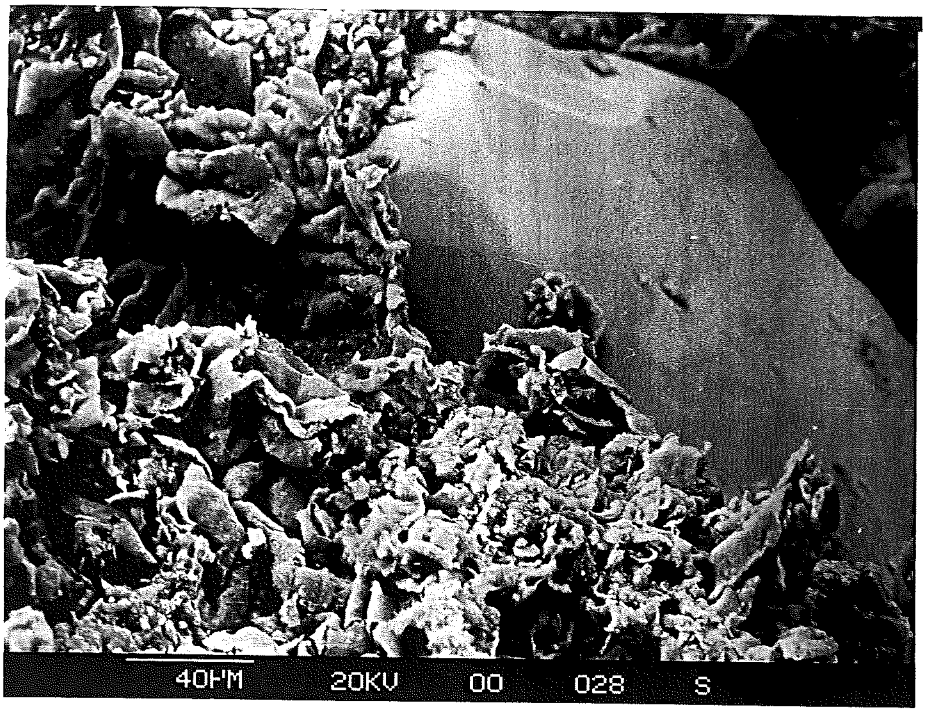


Figure 4.10: S.E.M. micrograph of an ignimbritic fine to medium SANDY SILT (BH6651, 55.28m - lower ignimbritic silt unit), before consolidation testing. The micrograph shows a fine sand sized quartz grain (identified by conchoidal fracture) supported by a 'flaky' matrix of irregular halloysite sheets. Void ratio = 2.66.

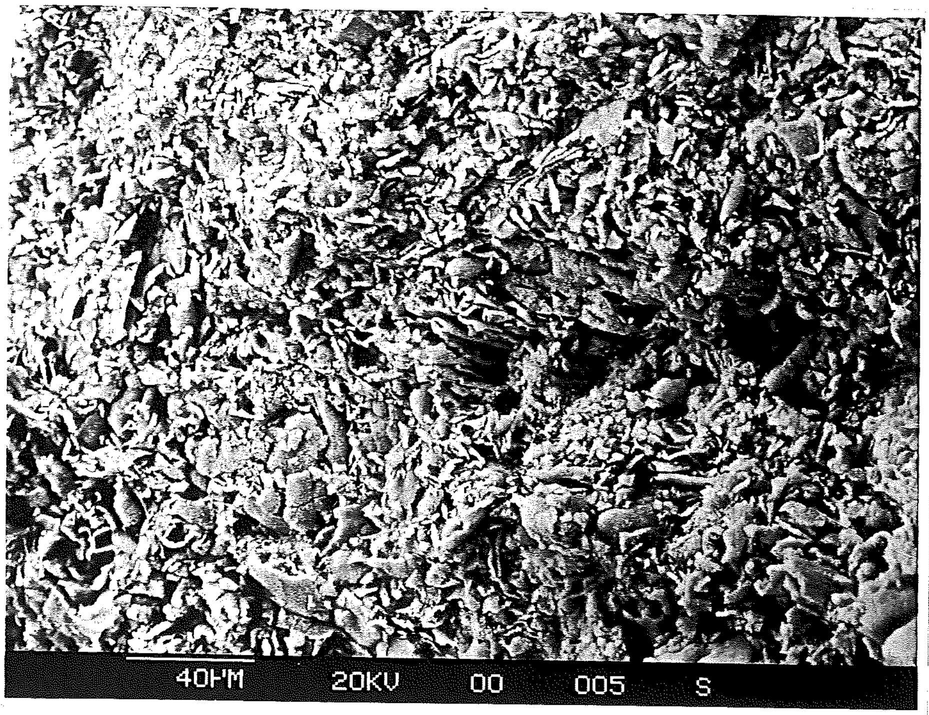


Figure 4.11: S.E.M. micrograph of the ignimbritic SANDY SILT shown in Figure 4.10, but after consolidation testing. As observed in Figure 4.9, a more compact arrangement and general breakdown of the matrix has occurred. Void ratio = 1.62.

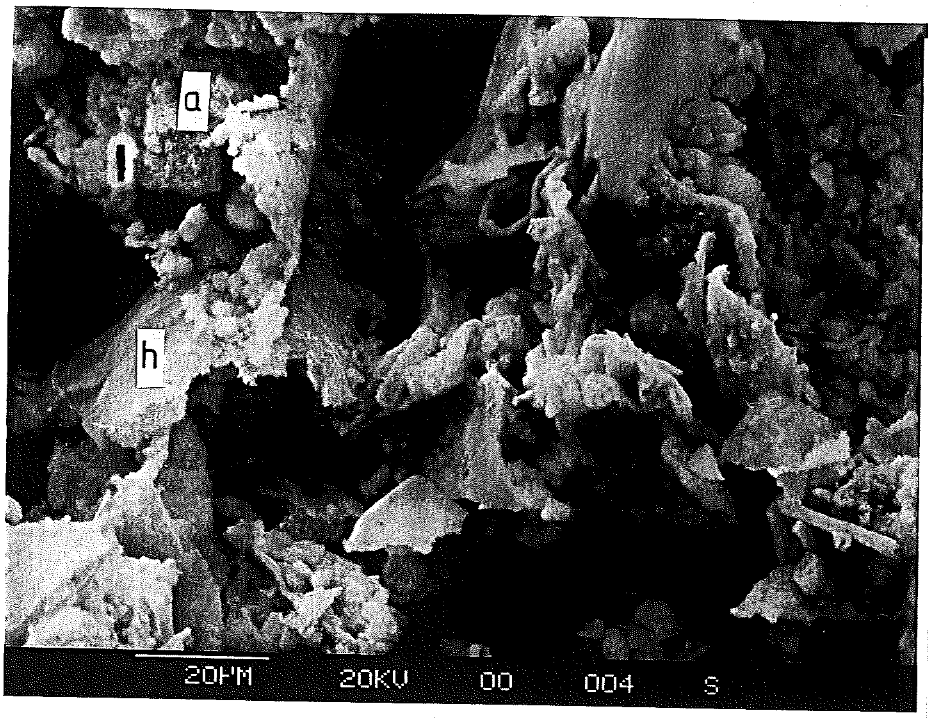


Figure 4.12: S.E.M. micrograph of an ignimbritic SANDY SILT (BH6651, 9.84m) at high magnification showing loosely packed aggregates of allophane (a - tentative identification) on curved halloysite sheets (h).

4.5.3 Interpretation and discussion

'Bulky' material structure with random 'loose' packing of particles can be seen in all micrographs of samples prior to consolidation testing. Void space is typically distributed through the materials as irregular 'cavities' and rarely as oval 'ducts' within the solids.

Solids identified within the sand fraction (60 to 200 μm) are quartz (Figure 4.10), pumice and glass shards (Figure 4.9) which are generally matrix supported. The matrix, of predominently silt size (2 to 60 μm) fragments exhibit flat and curved platy, nodular and tabular forms. These morphologies are consistent with a halloysite-kaolin mineralogy (Dixon, 1977; Lowe and Nelson, 1983) as identified by X.R.D. analyses (Section 4.3.2.4). Very fine (c. 1 m in diameter) loosely packed aggregates characteristic of allophane (Lowe, 1981) are tentatively identified from the upper ignimbritic silt unit (Figure 4.12).

No preferred particle orientation is observed within the ignimbritic silts which is consistent with the 'massive' field description of the materials, and similar values of permeability and compressibility in both horizontal and vertical directions (Sections 4.4.3 and 4.6.3).

Loading during one-dimensional consolidation testing of the ignimbritic silts typically extended to c.6 times their preconsolidation pressure. Both consolidated samples exhibit (Figures 4.9 and 4.11) a more compact arrangement and fragmentation of the silt matrix. Fractures within sand size pumice and quartz grains are also observed. The overall particle fragmentation is illustrated by Figure 4.13 where grain size distribution curves, before and after consolidation testing are plotted.

The 'open' texture illustrated in the ignimbritic silts has also been described by Carr (1981) in his S.E.M. study of the Matahina Ignimbrite, Bay of Plenty.

4.6 Permeability Testing

4.6.1 Introduction

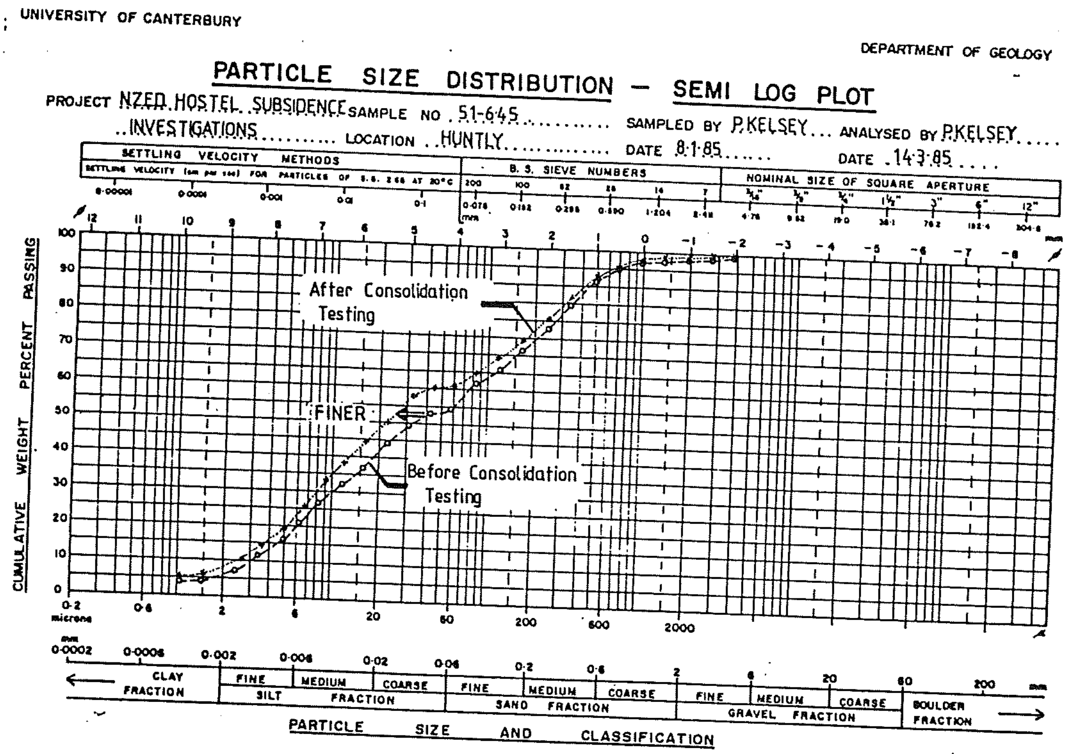


Figure 4.13: Particle grading curves for an ignimbritic fine to medium SANDY SILT (BH6651, 6.45m) showing material fragmentation with consolidation testing.

Permeability tests were undertaken for all materials within the Tauranga Group sequence from BH6651 (apart the from gravels and gravelly sands) to provide detailed data for the settlement-time analysis of Chapter Five. Samples were orientated from core in both vertical and horizontal directions to investigate permeability anisotropy.

4.6.2 Test Procedure and Results

A falling head apparatus was used for all tests in preference to the constant head equipment because of low expected material permeabilities as indicated by field tests (Section 3.5.2).

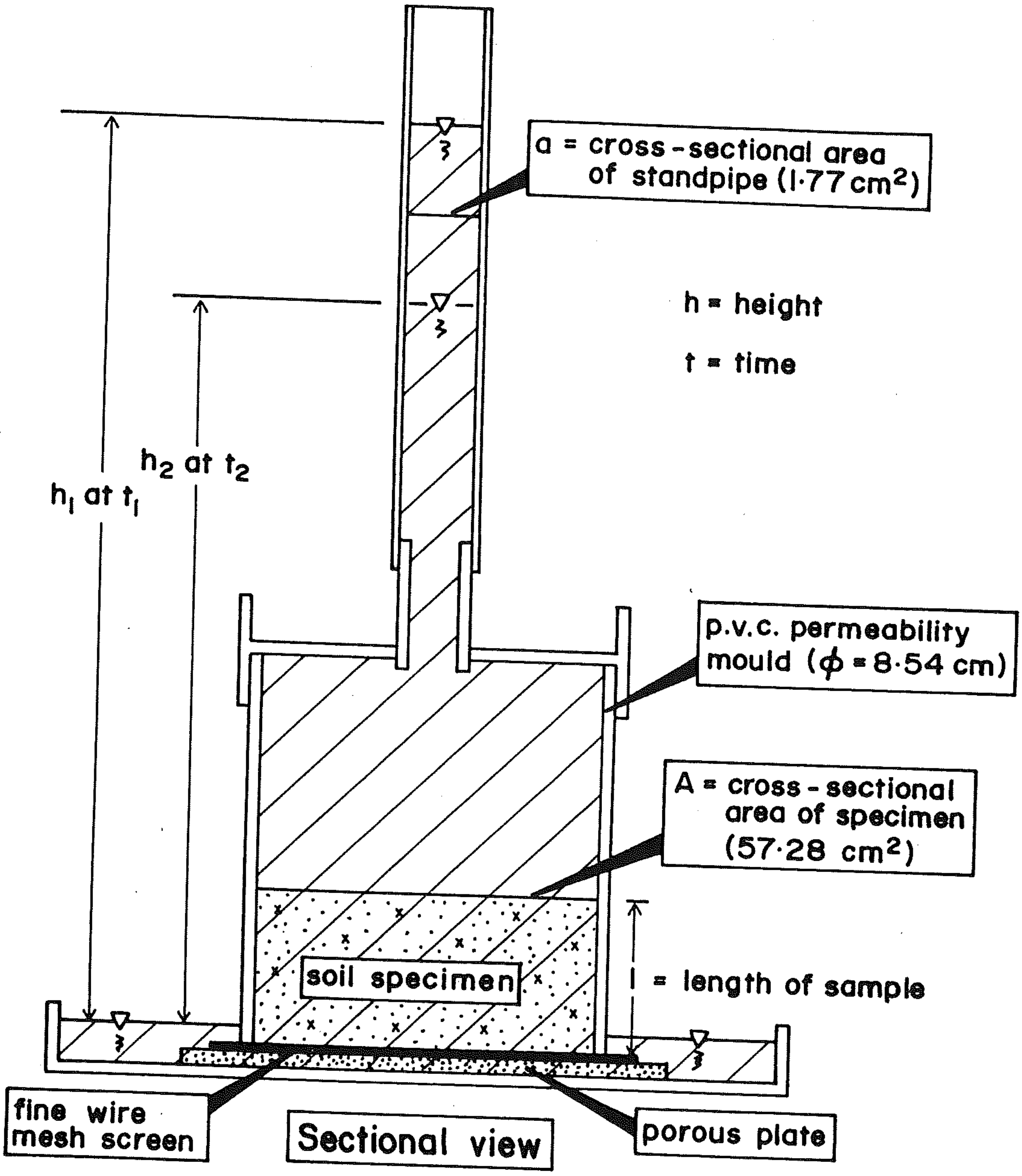
Test procedure follows that described by Vickers (1978) and Scott (1980). The undisturbed samples are initially trimmed by the permeability mould (to ensure no excess leakage at sample circumference) which is then filled with water and attached to a stand-pipe. A hydraulic head is then applied to the sample and its drop with time recorded. Test apparatus and permeability calculations are presented in Figure 4.14.

Samples were left in apparatus for up to 12 hours under flow conditions to ensure complete saturation of materials before permeabilities were estimated. Permeability determinations were made with varying changes of head, the average of these values being adopted as the result.

Results of all permeability tests are presented in Table 4.6. Due to sample trimming difficulties, the permeabilities of fluviatile silts could not be measured using the falling head apparatus. Permeabilities for these materials are calculated from one-dimensional consolidation test data and are presented in Table 4.7. Ranges of measured permeabilities are compared with S.C.M. Ohinewai data (Heu, 1983) in Table 4.8..

4.6.3 Interpretation and Discussion

The test results show that k values of the Tauranga



(Figure not to scale)

$$k = \frac{al}{A} \cdot \frac{\log_e (h_1/h_2)}{(t_2 - t_1)}$$

(adapted from Scott, 1980)

Figure 4·14: Apparatus and calculations for falling head permeability testing

TABLE 4.6: LABORATORY FALLING HEAD PERMEABILITY DATA FOR DH6651.

Sample Depth (m)	Material Description and Formation[1]	Permeability[2] (k_v, k_h in m/s)
6.22	Ignimbritic fine to medium SANDY SILT (K-H)	$k_v = 4.76 \times 10^{-7}$
9.74	Ignimbritic SILTY fine to medium SAND (K-H)	$k_v = 4.55 \times 10^{-7}$
10.00	Ignimbritic SILTY fine to medium SAND (K-H)	$k_v = 5.57 \times 10^{-7}$
10.15	Ignimbritic SILTY fine to medium SAND (K-H)	$k_h = 6.34 \times 10^{-7}$
10.40	Ignimbritic SILTY fine to medium SAND (K-H)	$k_v = 5.22 \times 10^{-7}$
10.25	Ignimbritic SILTY fine to medium SAND (K-H)	$k_h = 4.49 \times 10^{-7}$
13.00	Ignimbritic SILTY fine to medium SAND (Kp)	$k_v = 1.39 \times 10^{-6}$
13.43	Ignimbritic SILTY fine to medium SAND (Kp)	$k_v = 1.40 \times 10^{-6}$
19.00	Ignimbritic fine to medium SAND (Kp)	$k_h = 1.31 \times 10^{-5}$
19.10	Ignimbritic fine to medium SAND (Kp)	$k_v = 1.44 \times 10^{-5}$
22.60	Ignimbritic fine to medium SAND (Kp)	$k_h = 1.98 \times 10^{-5}$
22.90	Ignimbritic fine to medium SAND (Kp)	$k_v = 1.73 \times 10^{-5}$
39.75	Ignimbritic SILTY fine to medium SAND (Wg)	$k_h = 5.21 \times 10^{-7}$
43.75	Ignimbritic SILTY fine to medium SAND (Wg)	$k_v = 2.55 \times 10^{-6}$
55.40	Ignimbritic fine to medium SANDY SILT (Wg)	$k_h = 1.06 \times 10^{-7}$
55.50	Ignimbritic fine to medium SANDY SILT (Wg)	$k_v = 1.17 \times 10^{-7}$
59.00	Ignimbritic SAND fine to medium SAND (Wg)	$k_v = 1.60 \times 10^{-7}$
59.20	Ignimbritic.SAND fine to medium SAND (Wg)	$k_v = 1.89 \times 10^{-6}$
60.95	Fluviatile SILTY fine to medium SAND (Wg)	$k_v = 7.48 \times 10^{-7}$
66.40	SILTY CLAY (weathered Waikato Coal Measures Mudstone)	$k_v = 1.23 \times 10^{-10}$

1 Formation abbreviations (K-H) = Kauroa-Hamilton Ashes
(Kp) = Karapiro Formation
(Wg) = Whangamarino Formation

2 k_v = vertical permeability; k_h = horizontal permeability

TABLE 4.7: PERMEABILITIES OF FLUVIATILE SILTS, BH6651, DETERMINED FROM ONE-DIMENSIONAL CONSOLIDATION TEST DATA.

Material Description	Sample Depth (m)	Permeability k_v (m/s)
Fluviatile CLAYEY SILT with some sand (Wg)*	34.90	2.70×10^{-11}
Fluviatile SANDY SILT with some clay (Wg)	61.85	1.55×10^{-10}

* (Wg) = Whangamarino Formation

TABLE 4.8: COMPARISON OF LABORATORY AND S.C.M. (OHINEWAI) PERMEABILITY DATA

Texture	Laboratory permeabilities[1] (k_h and k_v in m/s)	Average values of S.C.M. (Ohinewai) data[2] (m/s)
SAND	(ignimbritic) 1.31×10^{-5} to 1.98×10^{-5} (4)[3]	1.72×10^{-5} (1)
SILTY SAND	(ignimbritic) 2.55×10^{-6} to 4.55×10^{-7} (9) (fluviatile) 1.89×10^{-6} to 7.48×10^{-7} (3)	3.05×10^{-7} (4)
SANDY SILT	(ignimbritic) 1.06×10^{-7} to 4.76×10^{-7} (2) (fluviatile) 1.55×10^{-10} (1)	1.80×10^{-7} (2)
CLAYEY SILT	(fluviatile) 2.70×10^{-11} (1)	1.0×10^{-8} (1)

1 Laboratory data from both falling head permeability one-dimensional consolidation testing.

2 Average measured k values from Heu (1983).

3 Number of permeability determinations.

Group sequence range from medium to very low (10^{-5} to 10^{-11} m/s) values of permeability. This range can probably be extended to 10^{-2} to 10^{-3} m/s for the highly permeable gravel lenses within the succession (Section 3.8.4).

Consistent permeabilities (c.10^{-7}m/s) are evaluated for the upper and lower ignimbritic silt rich units (BH 6651, at 6.22m to 10.25m and 55.40m to 55.50m). These values are contrasted by the relatively impermeable fluviatile silts where k ranges from c.10^{-10} to 10^{-11} m/s. The ignimbritic and fluviatile sands have similar k values, and are generally more permeable than the ignimbritic silts.

Vertical and horizontal permeabilities, apart from the samples of BH6651, 39.75m and 43.75m (Table 4.6) are approximately equal which is consistent with the massive nature of the materials observed from core (Appendix 2) and S.E.M. investigations (Section 4.5.3). The order of magnitude difference between k_h at 39.75 and k_v at 43.75 is interpreted as being due to the effects of subhorizontal 'flattened' pumice clasts (see BH6651 log, Appendix 2) which cause the higher horizontal permeability.

Variations in k values within the ignimbritic and fluvial sands, as indicated by field material descriptions (Appendix 2) are due to variations in silt content, material compaction and iron cementation.

The S.C.M. permeability data (Table 4.8) is in general agreement with k values of this investigation. The large differences between the laboratory and S.C.M. determinations for the (fluviatile) sandy silts and clayey silts is considered to be due to varying degrees of material compaction.

4.7 Synthesis: Implications of Laboratory Investigation to the Engineering Geological Model

In terms of the tentative engineering geological model shown in Figure 2.14, laboratory investigations have identified a highly compressible silt aquitard within the lower part of the Tauranga Group succession. The highly compressible nature of the ignimbritic silt is primarily due to its bulky, loose packing of particles as described by the

S.E.M. fabric study and inferred by high void ratios and natural water contents. As shown by the large scale cross-sections (Figures 3.17 and 3.18, in map pocket), the ignimbritic sandy and clayey silt ranges in thickness from c.4 to 10 metres and is extensive over the hostel site. No significant differences in consolidation parameters or material properties are observed between samples from the lower ignimbritic silt unit centrally to, and on the outer margins of the subsidence area.

The highly compressible ignimbritic silts are contrasted by the incompressible fluviatile silts which are distinctive in terms of their low void ratios and water contents.

The ignimbritic and fluviatile sands within the lower part of the Tauranga Group sequence exhibit moderate to low compressibility values.

Directional isotropy in terms of compressibility and permeability is illustrated for most materials within the Tauranga Group succession.

CHAPTER V

ANALYSIS OF ENGINEERING GEOLOGICAL MODEL

5.1 Introduction

The purpose of this chapter is to analyse the data collected during the field and laboratory investigations with respect to the tentative engineering geological model shown in Figure 2.14. The analysis aims to determine whether:

1) void migration from roof falls is able to extend close enough to the Tauranga Group aquifer to cause drainage.
2) dewatering consolidation of the lower Tauranga Group materials contributed to the subsidence observed at the hostel site.

5.2 Roof Failure

5.2.1 General Considerations

Redistribution of forces in the roof after mining, as modelled for an ideal situation is shown in Figure 5.1. The two basic modes of failure recognised are shear failure resulting from shear forces immediately adjacent to the pillars, and flexural failure due to bending forces central to the roof-span area (Morgan, 1973),

Morgan, in his study of roof problems sites conditions conducive to shear failure as; the presence of discontinuities such as joints and faults orientated to permit instability; high vertical stress either from a large overburden thickness or transferred from adjacent mine workings; high horizontal stress; plus pillars and floor which are 'stiff' in comparison to the roof.

Morgan summarises conditions conducive to flexural failure as; low ratios of horizontal to vertical stress; thinly bedded layers or layers that are separated along

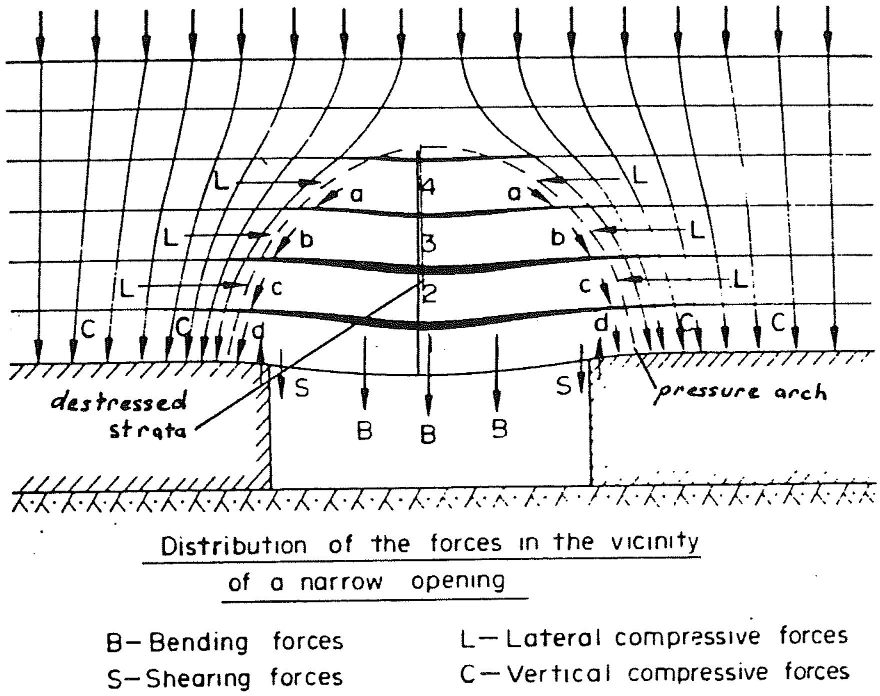


Figure 5.1: Sectional view of an idealised distribution of roof forces between two pillars (from Roberts, 1977). Possible failure modes are indicated by shear forces immediately adjacent to pillars (shear failure) and bending forces central to the roof-span area (flexural failure).

bedding planes; wide roof spans; jointing in the roof; and roof materials of low relative `stiffness'.

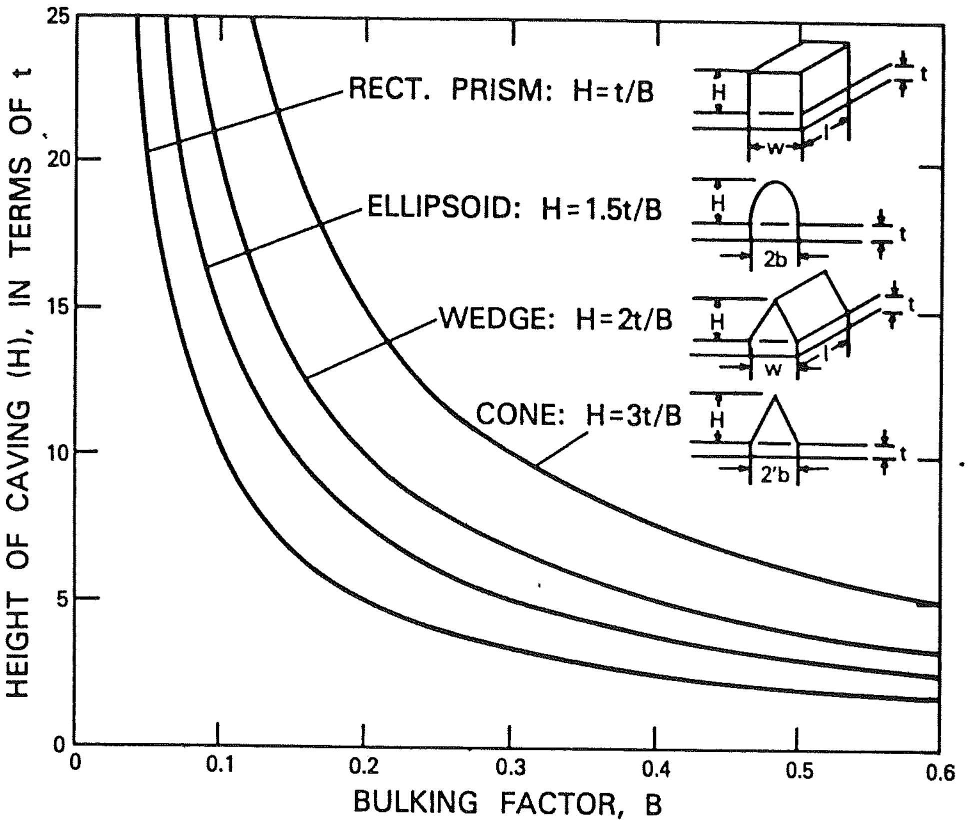
Once a rock fall has initiated, void migration will propagate upwards until equilibrium is achieved compatable with the existing gravitational and regional stresses, plus the physical properties of the overburden. Void migration is inhibited by; `competent' stratum in the overburden bridging the void; the formation of a `stable' pressure arch restricting the development of the de-stressed strata zone (Figure 5.1); and bulking of the collapsed material.

The effectiveness of void bridging within the overburden is dependent on the flexural strength of the spanning material. The height to which the pressure arch can extend is a function of room geometry and relative pillar stiffness (Alder and Sun, 1968). Ackenheil and Dougherty (1970) describe pressure arches attaining their maximum height at approximately twice the distance between the supporting pillars. Conditions of void bridging or stable arch development should always be considered temporary in terms of long term stability (St. George, 1982).

Determining the volumetric increase or bulking (Section 3.7) of the collapsed roof materials for a particular caving geometry, the height to which void migration can extend can be estimated. A graph, developed by Dunrud (1984), showing the relationship between maximum height of void migration and bulking for different caving geometries is shown in Figure 5.2.

Bulking factors for coal measure materials typically range from 0.3 to 0.5 (Piggot and Eynon, 1978) although values as low as 0.2 have been measured for soft claystones and shales (Dunrud and Osterwald, 1980). The most common caving geometry for room and pillar workings approximates an ellipsoid (consistent with `pressure arch' theory shown in Figure 5.1), although prism, wedge and cone geometries have also been recorded (Dunrud, 1984).

Using the typical bulking factor of 0.3 to 0.5, Figure 5.2 shows that the maximum height of void migration



$$B = \frac{V_c - V_o}{V_o}, \quad \begin{array}{l} V_o = \text{Volume of rock before caving} \\ V_c = \text{Volume of rock after caving} \end{array}$$

SAMPLE CALCULATION:

$$\text{ELLIPSE:} \quad B = \frac{[(4/3)(1/2)\pi Hb^2 + \pi b^2 t] - (4/3)(1/2)\pi Hb^2}{(4/3)(1/2)\pi Hb^2}$$

$$B = \frac{\pi b^2 t}{2/3 \pi H b^2} = \frac{t}{2/3 H}, \quad H = 3/2\, t/B = 1.5\, t/B$$

Figure 5.2: Maximum height of void migration for various caving geometries (from Dunrud, 1984, page 160, Figure 6). This graph shows the relationship between height of caving (H), in terms of thickness of coal mined (t), and the bulking factor (B) for various caving geometries. Sample calculation for one-half the volume of an ellipsoid of revolution is shown.

ranges from c.2t to 10t (where t is the thickness of coal mined). The estimated upper bound of 10t is consistent with field observations above room and pillar mines in New Zealand (Kelsey, 1980) and the United Kingdom (Taylor, 1975; St. George, 1982).

5.2.2 Roof Failures in the South Headings

On the basis of field evidence (Sections 2.3.3 and 3.7) roof instability is interpreted as being primarily flexural type failure with minor shear failure occuring as caving develops. Flexural failure is indicated by the location of virtually all roof falls at mine roadway intersections (Figures 2.3 and 3.16) where spanning distances are greatest. The exposure of bedding planes in the caving chimneys (Figure 3.16) is also consistent with this failure mode. The secondary shear failure mode was observed underground with blocks intermittently falling off the chimney walls along joints and shears.

The low regional values of in-situ horizontal stress as measured in the Huntly area (Mills, 1985) is listed by Morgan (1973) as one of the conditions conducive to flexural roof failure.

The geometry of south headings roof fall chimneys is approximately ellipsoidal as shown by Figures 3.16 and 2.10. This geometry, combined with the measured bulking factor of 0.3 (Section 3.7) when plotted in Figure 5.2 indicates that the maximum height of caving will be c.5t. This upper limit for panel 1 is estimated at 30m since the mine drive heights (t) range between 3.5m and 6.0m (Section 1.4.2).

In terms of the Tertiary overburden above panel 1 (Figure 3.19), the calculations indicate that the maximum caving height ranges between 5 and 25 metres below the Te Kuiti-Tauranga Group contact. The extension of caving to near the top and not through the Te Kuiti Group sequence is consistent with field evidence as there has been no record of Tauranga Group materials either in mine workings or as suspended solids in mine water discharge (Section 2.3.2).

5.3 Dewatering Consolidation

5.3.1 Conceptual Aspects

The effective (intergranular) stress ($\bar{\sigma}$) within saturated soil materials is equal to the total overburden stress (σ) minus the pore fluid pressure or neutral stress (μ).

$$\bar{\sigma} = \sigma - \mu \qquad \text{(Terzaghi, 1925)}$$

Terzaghi's equation shows that increased $\bar{\sigma}$ can result from load application (σ) or reduction in pore water pressure (μ).

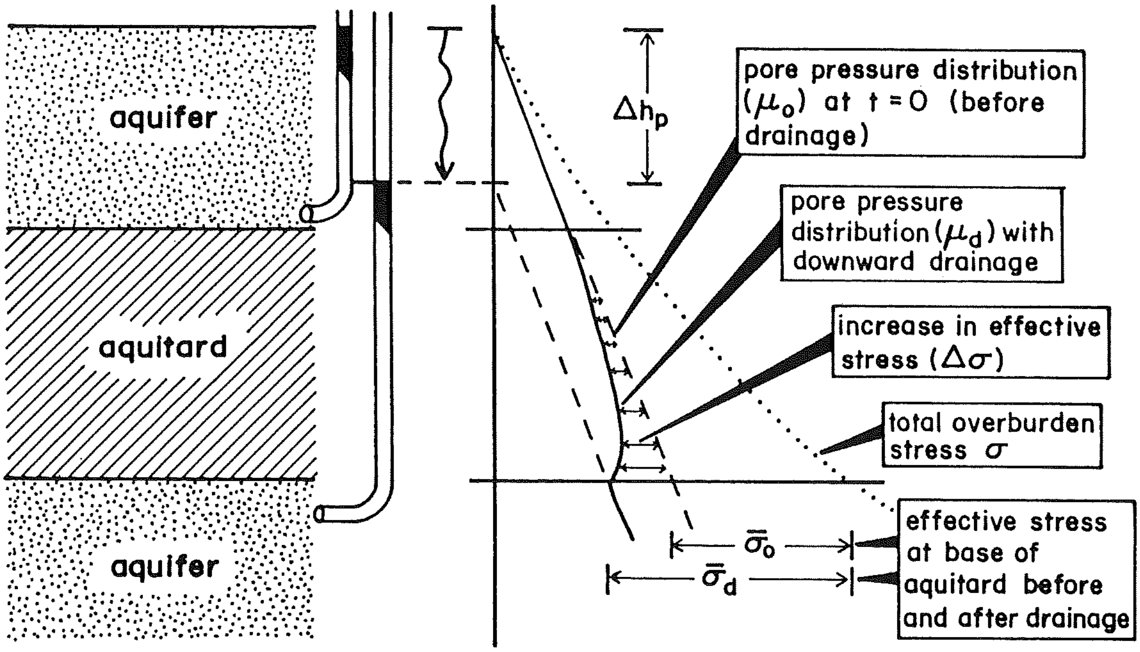
In terms of the engineering geological model (Figure 2.14), drainage at the base of the Tauranga Group sequence will cause dissipation of pore pressure (μ) which results in increased effective stress ($\bar{\sigma}$). The effects of drainage are schematically shown in Figure 5.3 for a confined aquifer overlain by an aquitard, a simplistic approximation of the lower Tauranga Group succession. The materials consolidate as a result of the increased effective stress, with the rate and magnitude of consolidation dependent on the soil's permeability and compressibility. These two factors are discussed with other consolidation parameters in Section 4.4.1.

Land subsidence due to groundwater withdrawal is a well documented phenomenon and is described world-wide by Poland (1972). Subsidence has also been related to the withdrawal of oil and gas (Poland and Davis, 1969), and geothermal fluid (Narasimhar and Goyal, 1984).

5.3.2 Back-analysis of Ultimate Settlement and Piezometric Head Drop

5.3.2.1 Analysis Procedure

The analytical approach taken assumes that the lower part of the Tauranga Group was normally consolidated prior to the hostel subsidence. The overconsolidation of these



Δh_p = pressure head drop with drainage

Figure 5·3: Ground water withdrawal from a confined aquifer overlain by an aquitard. Consolidation results from increase in effective stress ($\bar{\sigma}$) (adapted from De Simone and Viggiani, 1978).

materials (as measured by the one-dimensional consolidation tests - Section 4.4) is assumed to be attributable to increases in effective stress associated with dewatering. The analysis is restricted to two layers, the lower highly compressible ignimbritic silt and underlying less compressible silty sand (Figure A6.1) in Appendix Six.

The pre-subsidence ground level is calculated from estimates of the original thickness of the two layers. The piezometric head drop (Δh_p) is evaluated from the increase in effective stress (decrease in μ) inferred by the preconsolidation pressures.

The boundary conditions, a full list of assumptions, and calculations for the analysis are presented in Appendix Six.

5.3.2.2 <u>Results and Interpretation</u>

The relationship between assumed initial effective stress and measured preconsolidation pressure suggests an ultimate settlement of 894mm for the two consolidating layers. Measured settlement at E53, a precise levelling mark 20 metres away from borehole 6651 is 829mm. Thus, the observed and calculated magnitudes of ultimate settlement are in general agreement.

Estimated piezometric head drops at the mid-heights of each layer are 16.61m and 32.65m for the ignimbritic silt and underlying sand respectively. The maximum possible mid height piezometric head drops are c.41.0m for the ignimbritic silt and c.48.0m for the underlying sand. The lower calculated values of 16.61m and 32.65m indicate that only partial drainage of the consolidating layers has occurred. The difference in piezometric head drop between the two layers suggests that recharge and re-establishment of higher pore pressures took place in the sand before complete drainage of the ignimbritic silt.

These results and interpretations are tentative since it cannot be shown that the lower part of the sequence was originally normally consolidated, nor can the effects of 'apparent' overconsolidation (Section 4.4.3) be established with any certainty.

5.3.3 Back Analysis of Settlement Rates

5.3.3.1 Analysis Procedure

The multilayered nature of the Tauranga Group sequence does not allow evaluation of settlement rates using conventional Terzaghi one-dimensional consolidation theory. The approach adopted for the calculations uses an explicit one-dimensional finite difference analysis which calculates settlement for the layered sequence undergoing drainage from its bottom boundary.

The effects of aquifer recharge are not incorporated into the procedure, thus making the assessment of settlement rates conservative. However, since the lower aquifer in the Tauranga Group sequence (Section 3.8.4) at the hostel site is confined, the effects of recharge within this critical zone is considered negligible.

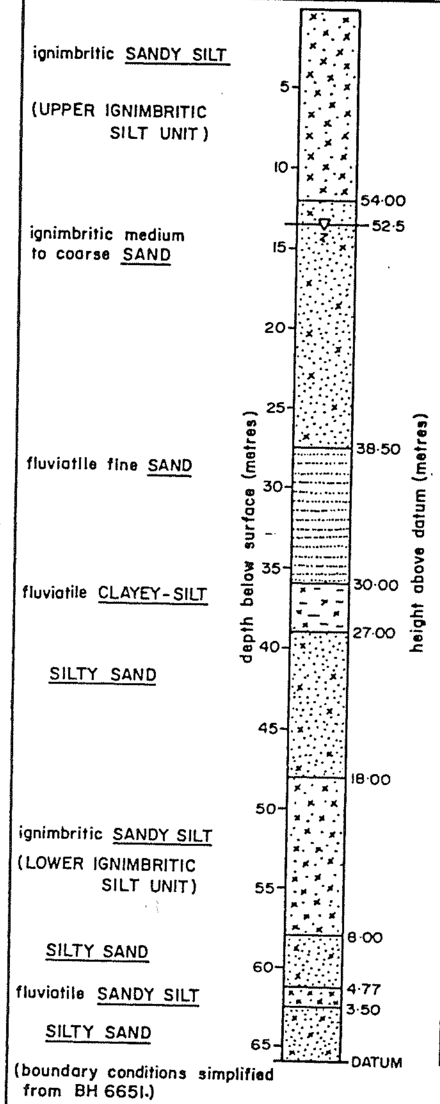
The theoretical basis for the finite difference analysis was developed by Drs R.O. Davis and B.W. Hunt of the Civil Engineering Department, University of Canterbury. This study used the theoretical basis to develop DECONS1 (dewatering consolidation), a Basic computer program for the finite difference solution. The theoretical basis, and a listing of DECONS1 is presented in Appendix Seven.

Values for the coefficients of compressibility (k) and permeability (a_v) are assumed to be constant throughout the analysis. Groundwater flow is assumed to be taking place under saturated conditions.

The input data and boundary conditions for DECONS1 are presented in Figure 5.4. The boundary conditions are interpreted from the summary log of Borehole 6651 (Appendix Two) and the a_v and k parameters used for input data are representative values from laboratory testing (Sections 4.4 and 4.6). The a_v values for layers 1, 3 and 4 are adjusted for the purposes of back analysis to represent initial normally consolidated conditions. The method of adjustment is shown in Appendix Five (BH6651, samples from 55.28m and 58.89m).

Gravels within the sequence, due to their high permeabilities are omitted because of numerical stability

BOUNDARY CONDITIONS AND INPUT DATA FOR 'CLOSEST FIT' SETTLEMENT - TIME CURVE

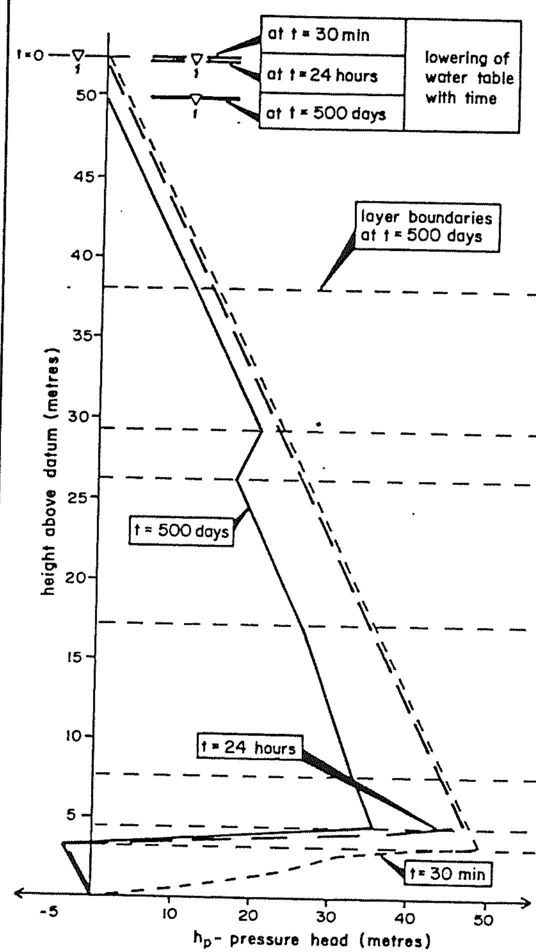


INPUT DATA FOR DECONS I

Layer number	zone height ΔZ_i (m)	number of zones in each layer Z	initial void ratio e_o	coefficient of permeability k (m/s)	coefficient of compressibility a_v (kPa⁻¹)
8	12·00	3	1·167	$1{\cdot}58 \times 10^{-5}$	$6{\cdot}29 \times 10^{-5}$
7	8·50	4	1·925	$2{\cdot}55 \times 10^{-6}$	$2{\cdot}05 \times 10^{-4}$
6	3·00	3	0·803	$1{\cdot}7 \times 10^{-8}$	$5{\cdot}50 \times 10^{-5}$
5	9·00	3	1·532	$2{\cdot}55 \times 10^{-6}$	$7{\cdot}25 \times 10^{-5}$
4	10·00	10	2·544	$1{\cdot}17 \times 10^{-7}$	$1{\cdot}08 \times 10^{-3}$
3	3·23	3	1·742	$4{\cdot}54 \times 10^{-7}$	$3{\cdot}66 \times 10^{-4}$
2	1·27	2	0·800	$1{\cdot}20 \times 10^{-9}$	$3{\cdot}00 \times 10^{-5}$
1	3·5	3	1·500	$2{\cdot}55 \times 10^{-6}$	$3{\cdot}66 \times 10^{-4}$

(selected from laboratory data - Section 4·4)

CALCULATED CHANGES OF PRESSURE HEAD AND MAGNITUDES OF VERTICAL COMPRESSION (at t = 500 days) FOR EACH LAYER



Layer number	Vertical Compression of each layer at t = 500 days (mm)
8	7
7	20
6	3
5	21
4	306
3	50
2	6
1	263
	676

Figure 5·4: Input parameters and calculated changes of pressure head and vertical compression using DECONS I requirements (Appendix Seven, Section 3.2). This omission is not considered significant in terms of the overall analysis since these materials are relatively incompressible (Lambe and Whitman, 1979), of limited thickness, and are laterally discontinuous.

DECONS1 evaluates settlement for any specified time period (target time) after drainage from the bottom boundary has commenced. By running the program for different target times, a settlement-time curve can be constructed.

The input data considered least reliable for DECONS1 are the permeability values of layers 2 and 6 (fluviatile silts). The permeabilities of these layers were estimated indirectly from the one-dimensional consolidation test data (Table 4.7). During the analysis, a number of settlement-time curves were constructed, adjusting k in layers 2 and 6 to investigate whether a close fit of the field curve could be made. The input data shown in Figure 5.4 lists the adjusted k values for the 'closest-fit' curve.

5.3.3.1 Results and Interpretation

The 'closest-fit' theoretical and observed field settlement-time curves are shown in Figure 5.5. As shown by Figure 5.4 the curve for E53 can be matched using realistic permeability values for layers 2 and 6.

The theoretical maximum and minimum rates of settlement are 271mm/day and 0.2mm/day respectively. Measured settlement rates on the basis of limited survey data for E53 range between 10mm/day and 0.6mm/day. The deviation of the E53 field curve from the theoretical curve during April 1983, is attributed to the effects of Phase II rapid subsidence (Section 2.2) where drainage possibly occurred at another location, from the base of the sequence.

As part of the estimation of settlement, DECONS1 calculates changes in void ratio, total water head, superficial water velocity and water table position. Output data from the program lists all these parameters for individual zones within layers present below the water table. Representative output data for the 'closest-fit' settlement time curve are presented in Appendix Eight.

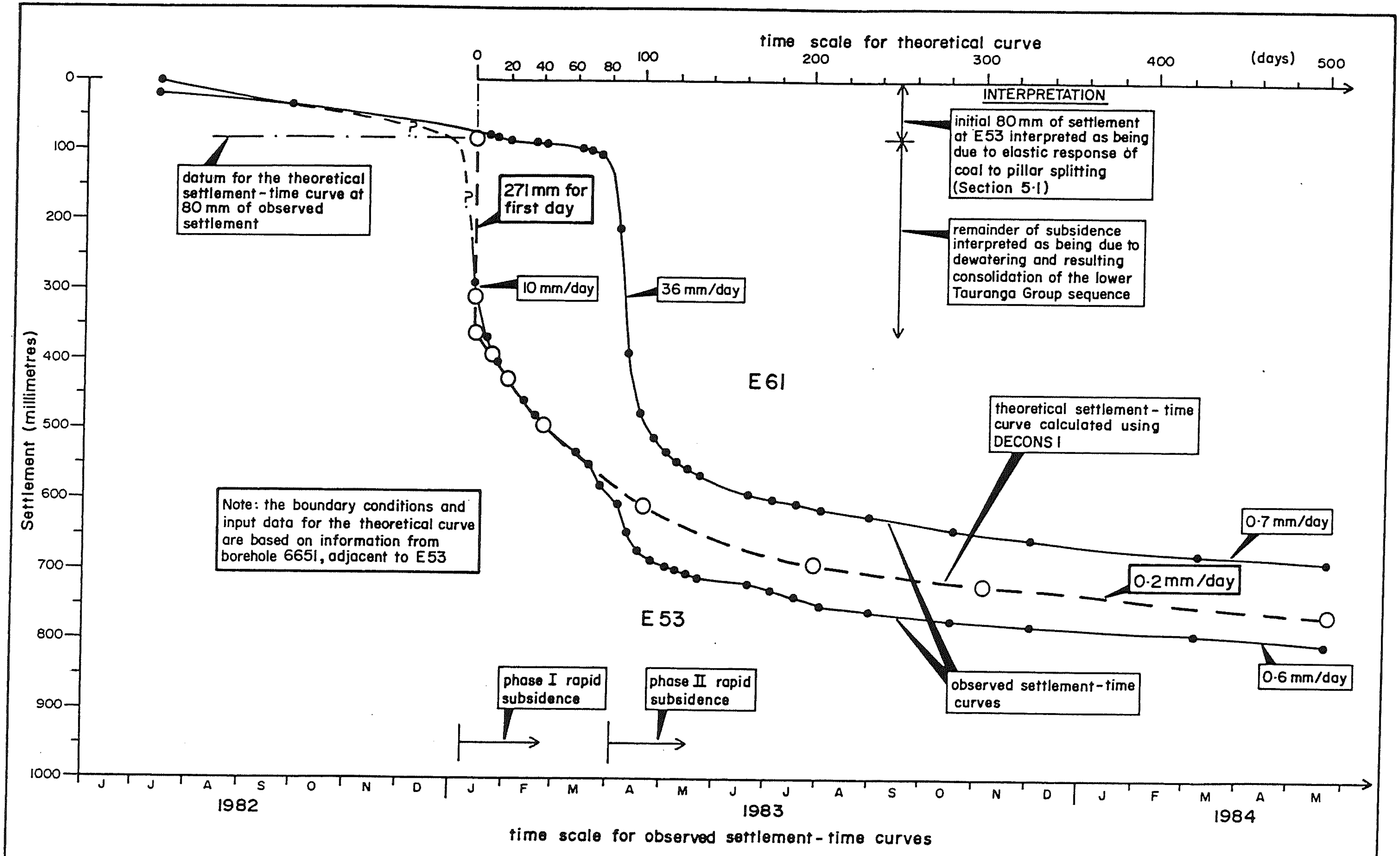


Figure 5·5: Comparison of observed and calculated rates of settlement for the hostel subsidence

One-dimensional drainage of the sequence can be expressed in terms of reduction of pressure head (h_p) with time. The pressure head distribution is plotted for the sequence at the target times of 30 minutes, 24 hours and 500 days in Figure 5.4. Vertical compression for each layer at the target time of 500 days is also plotted on Figure 5.4

Features to note from the pressure head and compression data presented in Figure 5.3 are:

1) the large changes (Δh_p = 52.5m, $\Delta\mu$ = 515kPa) of pressure head at the base of the sequence when drainage takes place.

2) the significant effect of the low permeability of layer 2 controlling pressure head dissipation.

3) the development of negative pressure head (up to c. -3.5m) in layer 1.

4) that the greatest compression occurs in the ignimbritic silt (layer 4) and the lower silty sand (layer 1).

One of the major implications of this analysis is that the fine grained materials of very low permeability limit the magnitude of pressure head dissipation within the sequence. For example if layer 2 was absent from the succession, much larger settlements would result.

5.4 Elastic Response of Mine Pillars

A minimum of 50mm of subsidence has occurred over all workings of the south headings (Figure 2.1). The subsidence takes place during and immediately after mining (Figure 2.3) and in interpreted by Depledge (1983a) as representing the elastic response of coal to pillaring. This 'immediate' subsidence has taken place prior to the rapid subsidence phases monitored above panels 1 and 3, as shown in Figure 2.1. The magnitudes of 'immediate' subsidence in these areas is measured as c.85mm for E53 and

90mm for E91 (Figure 2.1).

To account for subsidence related to the elastic response of coal to pillaring, the datum for the theoretical settlement-time curve is adjusted to 80mm of observed settlement (Figure 5.5).

CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Causes and Mechanisms of the Hostel Subsidence

The proposed engineering geological model, supported by field and laboratory investigations, and considered most likely in explaining the hostel subsidence is presented in Figure 6.1. The causes of ground movement defined by this model can be categorised into engineering geological, geotechnical and mining related factors.

6.1.1 Engineering Geological Factors

Engineering geological factors considered to have contributed to the hostel subsidence are:

1) the relief on the Te Kuiti-Tauranga Group contact and the structural position of the mined Kupakupa seam. Relief on the Te Kuiti-Tauranga Group contact (as defined by drilling), is dominated by a buried hill (-10m R.L.) to the east, gently sloping (c. 8^{o}) to a buried valley in the west (-45m R.L.). On this surface an east-west striking minor buried valley has also been delineated; and

2) panel 1, below the hostel, represents workings at the highest structural position in the southern headings. Structure contours for the mine floor in panel 1 range from -75m to -85m metres below sea level.

These two engineering geological factors provide the geometric constraints to the thickness of Tertiary overburden above mine workings. Over panel 1, coal measures material cover ranges from 35 to 50 metres.

6.1.2 Geotechnical factors

Geotechnical factors considered to have

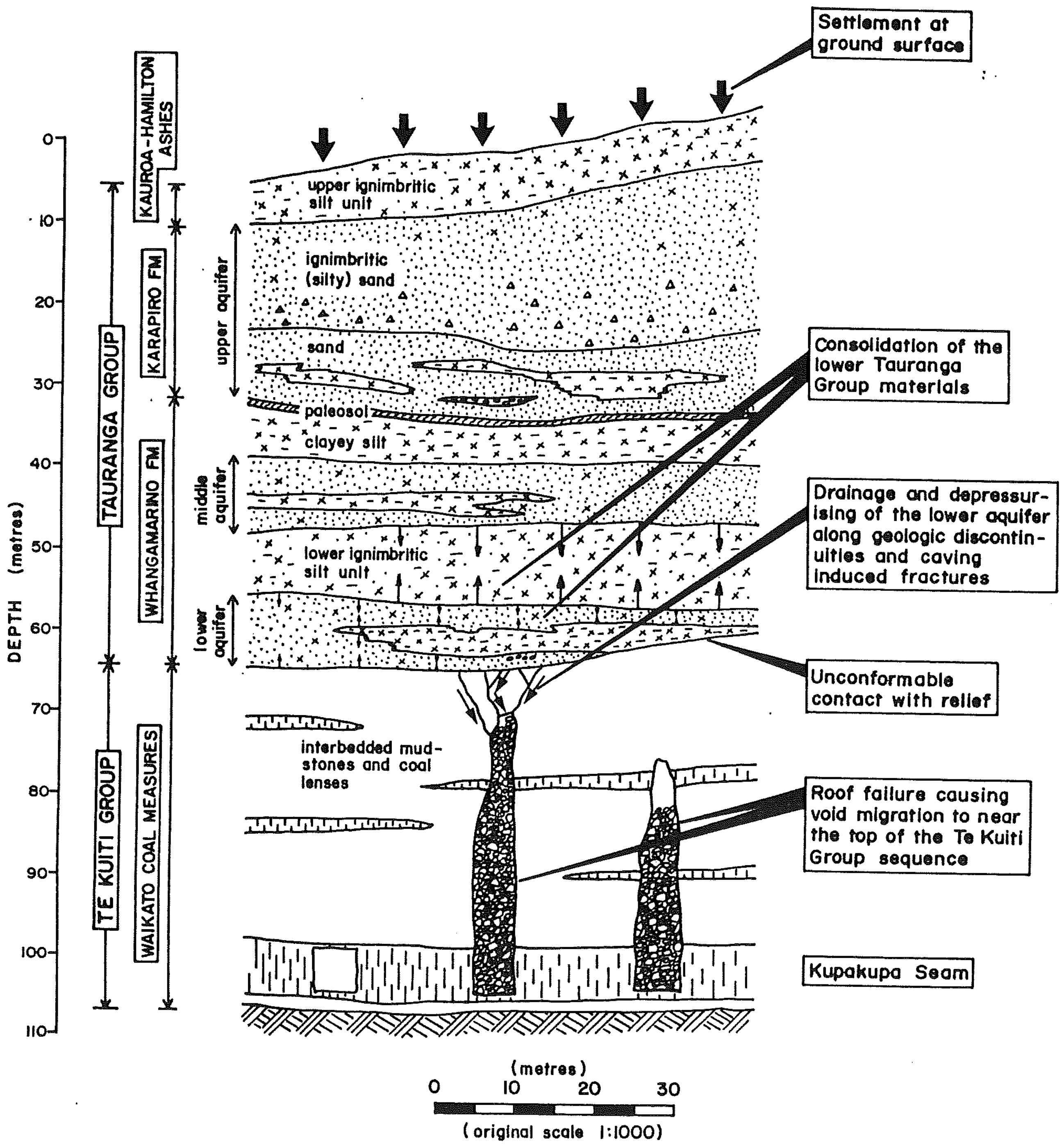


Figure 6·1 : Engineering Geological Site Model contributed to the hostel subsidence are:

1) the moderate to highly compressible materials identified at the base of the Tauranga Group sequence; and

2) the presence of an aquifer, associated with these materials, under high peizometric head.

Near the base of the highly pumiceous, typically well graded, interlayered Tauranga Group sequence, two compressible units are present. The compressible materials consist of an ignimbritic silt unit, c.4 to 10 metres thick which is transitional to an underlying ignimbritic silty sand c.1 to 2 metres thick. Both units are extensive over the hostel area as defined by drilling (Figures 3.17 and 3.18). The ignimbritic silt is highly compressible (Cc = 1.14 to 1.63) and is characterised by high void ratios (e = 2.07 to 2.77), high water contents (w = 70 to 134%) and low dry densities (p_d = 0.71 to 0.88 t/m^3). The underlying ignimbritic silty sand is moderately compressible (Cc = 0.76 to 0.97). Material permeabilities for the ignimbritic materials are typically low ($k_v = 10^{-7}$m/s), with both units comprising an aquitard above the lower aquifer.

The lower aquifer is interpreted as being confined and has a restricted distribution over the hostel site area. The piezometric head at the base of the aquifer, prior to any mining activity is considered to be c.53m.

6.1.3 Mining Related Factors

Factors related to mining activity considered to have contributed to the hostel subsidence are:

1) mine roof instability causing caving to near the top of the Te Kuiti Group sequence; and

2) possible elastic response of coal pillars during mining.

Roof failure and resulting caving chimneys have been been observed during the underground inspections by State Coal Mines in panel 1, below the hostel. Roof collapse in terms of void migration through the Te Kuiti Group sequence is summarised as part of the model analysis in Section 6.1.4.

Subsidence resulting from possible elastic response of coal pillars to mining is interpreted on the basis of surface monitoring data, where at least 50mm of settlement is measured above all mine workings of the south headings. This subsidence mechanism is speculative and further investigations are required to determine its nature and magnitude (Section 6.4).

6.1.4 Subsidence Mechanisms and Model Analysis

The primary mechanism of the hostel subsidence is identified as consolidation of materials within the lower part of the Tauranga Group sequence in response to mining induced dewatering. Considered to be of secondary importance is the possible initial subsidence response of the coal pillars to mining.

The bulking factor (volumetric expansion) of the coal measure materials is calculated at 0.3 from the underground mapping of a roof fall area. Using this factor and observations of caving chimney geometry, the estimated maximum height of caving is 5t (where t = the mined seam thickness) which is in accordance with comparative overseas studies. In terms of the Tertiary overburden above panel 1, the maximum caving height extends to between 5 and 25 metres below the Te Kuiti-Tauranga Group contact. It is considered likely that drainage (and resulting depressurisation) of the lower confined aquifer within the Tauranga Group took place along geological discontinuities or caving induced shear fractures.

Two one-dimensional back analysis procedures were adopted to compare calculated and observed magnitudes and rates of settlement. Both procedures use boundary conditions and geotechnical data from borehole 6651, in the area affected by maximum subsidence.

For the determination of ultimate settlement, the two compressible ignimbritic units are assumed to be normally consolidated prior to subsidence. The overconsolidation of these materials (as measured by oedometer testing) is assumed to be attributable to increases in effective stress associated with dewatering. Calculated ultimate settlement for the two consolidating layers is 894mm which compares well with the measured settlement of 829mm at E53, a levelling mark 20 metres away from borehole 6651. The calculations of ultimate settlement are considered tentative, since it cannot be shown that the lower part of the sequence was originally normally consolidated, nor can the effects of 'apparent' overconsolidation be established with any certainty.

The analysis of settlement rates uses a one-dimensional explicit finite difference numerical procedure, developed as part of this study. The analysis calculates settlement for the layered sequence undergoing drainage from its bottom boundary. The consolidation parameters for the compressible ignimbritic materials are adjusted for the purposes of back analysis to represent initial normally consolidated conditions. Using measured and estimated permeability values for the layered sequence, a close fit between observed and calculated settlement-time curves is attained. The theoretical maximum and mimimum rates of settlement are 271mm/day and 0.2mm/day respectively. Measured settlement rates on the basis of limited survey data at E53 range between 10mm/day and 0.6mm/day.

One of the major implications of the finite difference analysis is that fine grained materials of very low permeability limit the magnitude of pressure head dissipation and resulting consolidation within the sequence. If these materials were absent from the lower part of the Tauranga Group sequence, significantly larger settlements would result.

The effect of aquifer recharge is not incorporated into the finite difference analysis, thus making the assessment of settlement rates conservative. However, since the lower aquifer in the Tauranga Group sequence at the hostel site is confined, the effect of recharge within the critical zone of drainage is considered negligible.

The proposed model, although considered most probable in explaining the hostel subsidence, still requires further field verification, particularly observations related to mining induced drainage of the lower Tauranga Group materials. Suggested procedures for such field verifications are discussed in Section 6.4

6.2 Future Subsidence over the South Headings

In terms of the model presented in Figure 6.1, the potential exists for continued subsidence over the south headings of the Huntly East Mine.

A minimum of c.50mm (based on existing Lands and Survey Department surface monitoring) of subsidence can be expected above all future panels of the south headings. This component is interpreted as being due to the elastic response of coal with pillar splitting and is likely to occur during and immediately after mining in a particular area.

Greater magnitudes and rapid phases of subsidence, related to dewatering consolidation, and interpreted as causing the greater part of observed settlements above panels 1 and 3 (maximum observed settlement over these panels to the 24th June, 1985 is 1134mm at E91) is considered possible over existing and future workings of the south headings. Factors important in determining areas likely to be subject to this type of subsidence are:

1) whether the Tertiary overburden thickness is adequate to prevent caving chimneys (as a result of mine roof failure) from draining the lower part of the Tauranga Group sequence; and

2) whether the compressible materials exist within zones likely to be subject to aquifer drainage (and depressurisation).

A recommended zonation scheme over the south headings in terms of the minimum allowable Tertiary overburden thickness is discussed in Section 6.4.

The ignimbritic materials, because of their mode of origin were likely to have been extensive over the south headings area. However, subsequent erosion may mean a restricted present day distribution. Thus, although these materials are extensive beneath the hostel site, their presence elsewhere over the south headings area cannot be predicted without detailed subsurface information.

Panel 4, adjacent to the workings under the hostel is considered to be an area of potential dewatering consolidation subsidence since:

1) the highly compressible lower ignimbritic silt is described at the base of the Tauranga Group sequence above these workings in BH6652 (48.3m to 52.3m, Appendix 2).

2) the Tertiary overburden thickness, on the basis of extrapolated data (see Figure 3.19) is of a similar thickness to that described beneath the hostel site.

3) roof falls are observed (Figure 3.16) within the panel.

The geometry of the drained aquifer is important in determining the extent of the subsidence trough. It is thus possible that subsidence troughs related to dewatering consolidation can extend significantly beyond the area directly above the mine workings. This feature is observed with the area affected by the hostel subsidence (Figure 2.5 and 2.6) where limit angles (Section 2.2) extend up to 71^{o}.

The timing of subsidence related to dewatering consolidation after the mining of a panel is considered to be unpredictable and related to the rate at which caving extends through the Tertiary overburden. The two rapid phases of the hostel subsidence took place 5 and 8 months after mining in panel 1 was completed.

The likelihood of repeated rapid phases of subsidence over panels 1 and 3, according to the model, will depend on the extent to which the Lower Tauranga Group aquifers have depressurised with mining induced drainage. Model analysis (Section 5.3) indicates that the highly compressible ignimbritic silts have only been partially drained with the 1983 hostel subsidence. Thus, the potential exists for further rapid subsidence phases depending on the extent to which mining induced drainage extends into the base of the Tauranga Group sequence.

In part due to the difficulties of mine excess, mining subsidence related to either mine pillar or floor failure has not been investigated as part of this study. As a consequence, the preceding discussion has not incorporated these two failure modes. The limited subsurface data available from panel 1 does indicate that it is unlikely either pillar or floor failure have played a significant role in causing the subsidence observed.

6.3 Implications for Future Coal Mining in the Huntly Area

This study has identified highly compressible materials within the Tauranga Group sequence. Where mining activity is likely to dewater these materials, the highly compressible units should be defined, and where present incorporated into settlement predictions during the mine design stages.

Planned mining developments likely to involve dewatering of the Tauranga Group sequence include the longwall mines of Huntly East and West and the proposed Weavers extension and Ohinewai opencast mines.

6.4 Future Work

6.4.1 Further Verification of the Engineering Geological Model

Future investigations considered to be of greatest importance are those associated with the further verification and confirmation of the proposed engineering geological model. The suggested methods of verification are:

1) piezometric water level monitoring of the piezometers installed (as part of this study) into the lowest Tauranga Group aquifer immediately above panel 4.

2) underground inspection of mine workings under the areas of maximum subsidence in panels 1 or 3.

During site investigations, piezometers were installed into the middle aquifer above panel 4 (the lower aquifer is absent). Monitoring of piezometric water levels with possible future settlement will allow a direct observation of aquifer depressurisation. Ideally instrumentation should be installed for these piezometers to provide a continuous record of water level fluctuations.

Until further investigations are completed of workings under areas of maximum subsidence, the assessment of any pillar or floor instability which may have contributed to observed settlement cannot be made with confidence.

6.6.2 Zoning of Potential Dewatering Consolidation Subsidence Areas

A suggested empirical approach for delineating areas likely to be effected by dewatering consolidation above room and pillar workings is to combine an upper limit of chimney caving with the mine Tertiary overburden thickness. Such a zonation scheme would define areas where caving, resulting from roof falls is likely to induce drainage of the lower Tauranga Group sequence.

The estimation of an upper limit of caving requires further investigation of coal measures bulking factors and observations of caving chimney geometries as discussed in Sections 3.7 and 5.2. As a general rule, based on conservative estimates of coal measures bulking factors, the upper limit of caving is 10 times the seam thickness (St. George, 1982; Babcock and Hooker, 1977).

An isopach map, similar to the one constructed as part of this study and shown in Figure 3.19, of Tertiary overburden can be used to define areas less than the upper limit of caving. Within these areas the potential for dewatering consolidation subsidence exists.

6.4.3 Other Investigations

The common occurrence of roof falls observed in panels 1 and 4 requires a further reassessment of room and pillar design. A modifed room and pillar design reducing roof spanning distances at intersections was adopted after the hostel subsidence and has been used for panels 3 and 4. This modified design has failed to control roof instability.

The lack of geological data from the room and pillar workings has hindered the identification of geologically related factors to the hostel subsidence. It is recommended that geological mapping combined with room and pillar design for roof stability.

An underground investigation programme determining the magnitude of immediate subsidence related to the elastic response of coal to pillaring is also recommended. Such a programme would involve the monitoring of both pillars (with borehole extensometer measurements) and roadways (with convergence measurements) during and after mining.

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APPENDIX 1: GLOSSARY OF TERMS

Aquifer: an aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield signifcant quantities of water to bores and springs.

Confining Bed: a confining bed is a body of impermeable material stratigraphically adjacent to one or more aquifers. In nature its permeability may vary from zero (aquiclude) to some value distinctly lower than that of the aquifer (aquitard).

Crown Holes: holes at the ground surface that result from void migration associated with mine roof failure. Those features commonly approximate a circular outline in plan and in section resemble an upright truncated cone.

Hydrostatic Response Time: hydrostatic time lag between increase in pore pressure of monitored material to increase in piezometric head as measured in a piezometer.

Settlement: measured or calculated component of downward ground movement.

Subsidence: downward ground movement.

APPENDIX 2: Detailed Lithology and Summary Logs

LOG OF DRILL HOLE

HOLE NO. 6651

PROJECT Huntly Subsidence FEATURE NZED Hostel LOCATION Hostel Grounds
GRID REF. 625 987.10 335 490.70 M.W.D. CO-ORD. DATUM Geodetic H.A.D. GROUND 21.73
ANGLE FROM HORIZONTAL 090° DIRECTION PHOTO NO. H.A.D. COLLAR

Formation	Description of core	Depth (m)	Rock structures (defects) / soil description	Water level
Kauroa - Hamilton Ash	ORGANIC TOPSOIL			
	LIGHT YELLOWISH GREY CLAYEY SILT WITH SOME COARSE SAND		moist; hard; massive; mottled; MH	
Upper Silt Unit	IGNIMBRITIC LIGHT REDDISH YELLOW PUMICEOUS SANDY SILT WITH SOME CLAY	1	gradational boundary	
			moist: soft & firm; massive; MH	
		2	Liesegang rings - jarosite?	
		3	colour change gradational	
	IGNIMBRITIC LIGHT GREYISH YELLOW PUMICEOUS SANDY SILT WITH SOME CLAY	4	manganese (?) nodules common	
		5		11-1-85
		6	quartz-rich sand horizon / white clayey silt } bedding subhorizontal	
			manganese (?) nodules common 0.3-1.0 cm Ø	
	LIGHT YELLOWISH BROWN FINE GRAVELS WITH SOME MEDIUM SAND	7	wet; loose; massive; rock fragments - Tauranga Group silts, pumice, rhyolite GP	
Upper Ignimbritic	IGNIMBRITIC LIGHT GREYISH YELLOW PUMICEOUS SILTY FINE TO MEDIUM SAND WITH SOME CLAY	8	moist to wet; firm; massive; mottled MH-SM	
		9		
		10		
		11	gradational boundary (boundary well defined with penetrometer soundings)	
Karapiro Formation	LIGHT OLIVE YELLOW PUMICEOUS SILTY FINE TO MEDIUM SAND (IGNIMBRITIC		moist to wet; compact; massive; sand, quartz-feldspar-pumice; SM-SW	
		12	quartz-feldspar rich beds 3-4 mm thick. Bedding 016°	
			pumice granules common 0.5 cm Ø	
		13	slight yellowish brown Fe-oxide weathering.	14-1-85
		14		

WEATHERING: UW - Unweathered; SW - Slightly weathered; MW - Moderately weathered; HW - Highly weathered; CW - Completely weathered

HARDNESS: VH - Very hard; H - Hard; MH - Moderately hard; MS - Moderately soft; S - Soft; VS - Very soft

FRACTURE LOG (cms) Spacing of natural fractures / Fractures/m of core

DRILLER: T. Brown
STARTED: 8·1·85
FINISHED: 14·1·85
DRILL: Failing 1250

EXPLANATION
0-5.0 m Wash drilled
5.0-67.25 m Cored (150 mm Ø)
Zones of core loss interpreted from geophysical logs

LOGGED: P. KELSEY DATE: 8-14.1.85 TRACED: CHECKED: P. KELSEY VERTICAL SCALE: 1:50
PROJECT: HOLE NO: 6651 LENGTH: 67.25 CORE BOXES:
SHEET 1 OF 6 DRG NO.

EQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6651

PROJECT: HUNTLY SUBSIDENCE
FEATURE: N.Z.E.D. HOSTEL
LOCATION: HOSTEL GROUNDS
GRID REF.: 625 987.10 335490.70
M.W.D. CO-ORD.:
DATUM: GEODETIC
ANGLE FROM HORIZONTAL: 090°
DIRECTION:
H.A.D. GROUND: 21.73
PHOTO NO.:
H.A.D. COLLAR:

DESCRIPTION OF CORE (FORMATION NAME; ROCK OR SOIL TYPE; DESCRIPTION OF CORE: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	DEPTH H A D (m)	ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc)
KARAPIRO FORMATION		
IGNIMBRITIC. LIGHT YELLOWISH WHITE PUMICEOUS SILTY FINE TO MEDIUM SAND WITH SOME GRANULES.	15–19	moist; compact; massive; SM
LIGHT BROWNISH YELLOW PUMICEOUS FINE TO MEDIUM SAND WITH SOME SILT AND GRANULES (IGNIMBRITIC)	19	0.1m Light brownish yellow medium-coarse sand SP
	19	moist; compact; massive; mottled, sand-quartz, feldspar + pumice SM-SP
	20–21	Fe-oxide band 45°-jarosite?
	21–22	pumice granules common up to 1.5 cm ø
	22–23	Fe-oxide bands 60°-jarosite?
	24	sand quartz-feldspar dominant, little pumice
	25	Fe-oxide "hard-pan"
LIGHT GREYISH YELLOW PUMICEOUS FINELY LAYERED FINE SAND (FLUVIATILE)	25	wet; compact; finely layered (25mm); sand-quartz, feldspar, pumice SP
	25	contact 60°
	26	bedding sub-horizontal.
LIGHT YELLOWISH BROWN SANDY FINE GRAVELS WITH SOME SILT	27–28	moist; compact; massive; gravels greywacke, GM
LIGHT OLIVE GREY PUMICEOUS SANDY SILT WITH SOME CLAY	28	moist; hard; massive; MH
	28	gradational boundary
LIGHT YELLOWISH WHITE PUMICEOUS MEDIUM TO COARSE SAND	28	moist, compact; finely layered; sand pumice rich. SP
LIGHT OLIVE GREY PUMICEOUS MEDIUM TO COARSE SAND	28–29	graded bedding cm scale
	29	gradational boundary
LIGHT YELLOWISH BROWN MEDIUM TO COARSE SAND	29	moist; compact; finely layered; pumice rich sand; dark yellowish brown Fe-oxide "hard-pan" at top of unit SP

Other column headings: WEATHERING (SW, MW, HW); HARDNESS (H, MH, MS, S); POINT LOAD TEST (kPa); CORE LOSS / LIFT (%) (5, 10, 50); Core size, casing; GRAPHIC LOG; FRACTURE LOG (Spacing of natural fractures) (50, 10, 5 cms); DATE/DEPTH; R.Q.D. %; WATER LEVEL (Date); DRILL WATER LOSS % (0–100); WATER PRESSURE TESTS Permeability - LUGEONS (.01, .1, 1, 10, 100, 1000)

Depth scale: 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29

DRILLER: T. BROWN
STARTED: 8.1.85
FINISHED: 14.1.85
DRILL: FAILING 1250

WEATHERING
UW - Unweathered
SW - Slightly weathered
MW - Moderately weathered
HW - Highly weathered
CW - Completely weathered

HARDNESS
VH - Very hard
H - Hard
MH - Moderately hard
MS - Moderately soft
S - Soft
VS - Very soft

FRACTURE LOG (cms): 100, 50, 10, 5, 1, 0.1 Spacing of natural fractures; 1, 2, 10, 20, 100, 1000 Fractures/m of core

EXPLANATION
Zones with core loss interpreted from geophysical logs.
15.00-30.00 Cored (150 mm ø)

LOGGED: P. KELSEY
DATE: 8-14.1.85
TRACED:
CHECKED: P. KELSEY
VERTICAL SCALE: 1:50
PROJECT:
HOLE NO: 6651
LENGTH: 67.25
CORE BOXES:
SHEET 2 OF 6
DRG NO

SQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6651

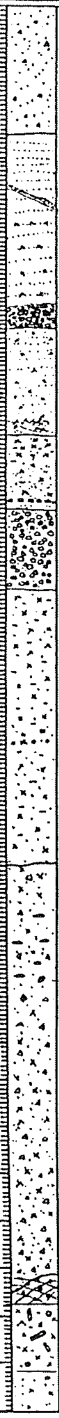
PROJECT *Huntly Subsidence* FEATURE *N.Z.E.D. Hostel* LOCATION *Hostel Grounds*

GRID REF. *625 987.10 335 490.70* M.W.D. CO-ORD. .... DATUM *Geodetic* H.A.D. GROUND *21.73*

ANGLE FROM HORIZONTAL *090°* DIRECTION .... PHOTO NO. .... H.A.D. COLLAR ....

Formation	DESCRIPTION OF CORE (Formation name; Rock or soil type; Description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	ROCK STRUCTURES (Defects) — Joints, veins, seams, shatter, shear & crush zones; foliation, schistosity (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.)
KARAPIRO FORMATION	LIGHT OLIVE WHITE PUMICEOUS MEDIUM TO COARSE SAND WITH SOME GRANULES	moist-wet; loose; massive; sand pumice rich (minor quartz feldspar and other volcanic lithics) in comparison 29.0-30.0 m. SP
	LIGHT OLIVE GREY PUMICEOUS FINE SAND WITH MINOR INTERBEDDED SANDY SILT. (FLUVIATILE)	moist-wet; loose; finely layered. SP-SM Fe oxide band 3mm thick Graded bedding common Bedding subhorizontal
	DARK GREY AND LIGHT YELLOWISH BROWN MEDIUM SANDY FINE TO MEDIUM GRAVELS	wet; loose; massive; gravels - greywacke and rhyolite (subrounded) GM
	YELLOWISH BROWN SILTY FINE SAND	moist, compact/cemented finely layered - subhorizontal SD Base Fe-oxide cemented graded bedding Contact 020°
UHANGAMARINO FORMATION	PALEOSOL DARK BROWN CLAYEY SILT WITH SOME MEDIUM TO COARSE SAND.	moist; hard; massive; organic rich CL transitional boundary
	LIGHT GREENISH GREY SILTY FINE TO MEDIUM SAND	moist, compact; massive SM
	LIGHT BLUE GREEN SANDY FINE-MEDIUM GRAVELS (FLUVIATILE)	wet-saturated; loose; massive; gravels - rhyolite, obsidian, greywacke very poorly sorted GM-GW
	LIGHT BLUISH GREEN CLAYEY SILT WITH SOME FINE TO MEDIUM SAND (FLUVIATILE)	moist; stiff to hard; massive upper contact horizontal. CL bedding subhorizontal defined by sand rich and sand poor layers granules greywacke
	IGNIMBRITIC LIGHT BLUE GREY PUMICEOUS SILTY FINE TO MEDIUM SAND WITH SOME GRANULES	highly vesicular flattened pumice granules 7cm organic carbonaceous fragments (charcoal) moist-wet; compact; massive; sand-pumice, quartz, feldspar plus minor rhyolite SW pumice fragments up to 2.5cm ø graded bedding granules 1cm ø more common at base unit dark blue green at base (Fe cementation ?)
	LIGHT GREYISH WHITE PUMICEOUS CLAYEY SILT (FLUVIATILE)	moist; hard; massive; fissured; fissures slickensided; MH wood fragments common 5cm length organic brown clay at base

Depth H.A.D.: 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44



Column headings: SW MW HW WEATHERING; H MH MS S HARDNESS; POINT LOAD TEST (kPa); CORE LOSS/LIFT % (5 10 50); DEPTH H.A.D. (Core size, casing); GRAPHIC LOG; FRACTURE LOG (Spacing of natural fractures) 50 10 5 cms; DATE/DEPTH; R.Q.D. %; WATER LEVEL (Date); DRILL WATER LOSS % (0-100); WATER PRESSURE TESTS Permeability - LUGEONS (.01 .1 1 10 100 1000)

DRILLER: *T. Brown*	WEATHERING UW - Unweathered SW - Slightly weathered MW - Moderately weathered HW - Highly weathered CW - Completely weathered	HARDNESS VH - Very hard H - Hard MH - Moderately hard MS - Moderately soft S - Soft VS - Very soft	FRACTURE LOG (cms) 100 50 10 5 1 0.1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core	LOGGED: *P. Kelsey* PROJECT: .... DATE: *8.1.85* HOLE NO: *6651*
STARTED: *8.1.85*	EXPLANATION			TRACED: .... LENGTH: *67.25*
FINISHED: *14.1.85*	Zones with core loss interpreted from geophysical logs			CHECKED: *P. Kelsey* CORE BOXES: ....
DRILL: *Failing 1250*	30.00-45.00 Cored (150 mm ø)			VERTICAL SCALE: *1:50*
				SHEET *3* OF *6* DRG NO ....

EQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6651

PROJECT: Huntly Subsidence — FEATURE: NZEQ Hostel — LOCATION: Hostel Grounds

GRID REF. 625987:10 335490:70 — M.W.D. CO-ORD. — DATUM: Geodetic — H.A.D. GROUND 21.73

ANGLE FROM HORIZONTAL: 090° — DIRECTION — PHOTO NO. — H.A.D. COLLAR

Columns: DESCRIPTION OF CORE (FORMATION NAME; ROCK OR SOIL TYPE; DESCRIPTION OF CORE: grain size, texture, mineral content, hardness, strength, cement & matrix colour) | WEATHERING (SW MW HW) | HARDNESS (H MH MS S) | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % (5 10 50) | DEPTH H.A.D. (Core size, casing) | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms) | ROCK STRUCTURES (Defects) JOINTS. VEINS. SEAMS: SHATTER, SHEAR & CRUSH ZONES: FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.) | DATE/DEPTH | R.Q.D. % | WATER LEVEL (Date) | DRILL WATER LOSS % (0-100) | WATER PRESSURE TESTS Permeability - LUGEONS (·01 ·1 1 10 100 1000)

Formation: WHANGAMARINO FORMATION

Unit: LOWER IGNIMBRITIC SILT UNIT

Depth (m)	Description of core	Rock structures / soil description
45–46	DARK OLIVE GREY PUMICEOUS SILTY FINE-MEDIUM SAND WITH SOME GRANULES	light grey wet - saturated; compact; SW
		dark grey
		WOOD; Black, moist, hard, fibrous, fractured
46	DARK OLIVE GREY MEDIUM SAND AND SOME SILT	moist - saturated; compact; well sorted; SP
		Bedding 9°-11° in sand.
46–47	LIGHT BLUE-GREEN CLAYEY SILT (FLUVIATILE)	moist; stiff - hard; massive; top of Unit dark brown and carbonaceous MH
		transitional boundary
47–48	WHITISH GREEN SILTY MEDIUM TO COARSE SAND	moist - wet; compact; massive; SM-SC
48	LIGHT GREYISH GREEN PUMICEOUS CLAYEY SILT (IGNIMBRITIC)	horizontal contact, dark green Fe-cement? band
		moist, hard; massive MH
50–51	IGNIMBRITIC LIGHT BLUE GREEN PUMICEOUS SANDY SILT WITH SOME CLAY	vugs 1-2mm ø, interconnected
		moist - wet; stiff - hard; massive MH-SM
51–52		bedding 10° defined by dark grey bands cm thick. 0.5-1.0 cm relief on bedding.
52		38°
		60°
52–53	IGNIMBRITIC MOTTLED LIGHT YELLOW BROWN - LIGHT BLUE GREEN PUMICEOUS SANDY SILT WITH SOME CLAY	62° 44° No weathering on fractures sandy silt soft 2mm either side of fractures. (drilling induced since barrel filled past capacity)
54		highly angular silt inclusions (concretionary ?)
54–58		"EASY" PENETRATION WITH DRILLING
56–57	IGNIMBRITIC LIGHT GREEN GREY PUMICEOUS FINE TO MEDIUM SANDY SILT WITH SOME CLAY.	wet; stiff - hard; massive; MH
57		70°
		60°
58		transitional boundary
59–60	IGNIMBRITIC LIGHT GREEN GREY PUMICEOUS SILTY FINE TO MEDIUM SAND	wet - saturated; compact, well sorted; SM-SC
60		Dark green banding Fe cementation?

Depth scale: 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59

DRILLER: T. BROWN

STARTED: 8.1.85

FINISHED: 14.1.85

DRILL: FAILING 1250

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms): 100 50 10 5 1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION

Zones with core loss interpreted from geophysical logs

45.00 - 60.00 cored (150mm ø)

LOGGED: P. KELSEY — DATE: 8-14.1.85 — TRACED: — CHECKED: P. KELSEY — VERTICAL SCALE: 1:50

PROJECT: — HOLE NO: 6651 — LENGTH: 67.25 — CORE BOXES:

SHEET 4 OF 6 — DRG NO.

NQ 3/25 M

LOG OF DRILL HOLE

PROJECT: Huntly Subsidence | FEATURE: N.Z.E.D. Hostel | LOCATION: Hostel Grounds | HOLE NO.: 6651

GRID REF.: 625 987.10 335490.70 | M.W.D. CO-ORD.: | DATUM: Geodetic

ANGLE FROM HORIZONTAL: 090° | DIRECTION: | H.A.D. GROUND: 21.73

PHOTO NO.: | H.A.D. COLLAR:

DESCRIPTION OF CORE — FORMATION NAME: ROCK OR SOIL TYPE: DESCRIPTION OF CORE: (grain size, texture, mineral content, hardness, strength, cement & matrix colour). | WEATHERING (SW, MW, HW) | HARDNESS (H, MH, MS, S) | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % | DEPTH H.A.D. | Core size, casing | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) cms | **ROCK STRUCTURES (Defects)** JOINTS: VEINS, SEAMS; SHATTER, SHEAR & CRUSH ZONES, FOLIATION; SCHISTOSITY (attitude, thickness, spacing, smoothness) **(OR SOIL DESCRIPTION)** (consistency, compactness, water content, group symbol etc.) | DATE/DEPTH | R.Q.D. % | WATER LEVEL Date | DRILL WATER LOSS % 0–100 | WATER PRESSURE TESTS Permeability – LUGEONS .01 0.1 1 10 100 1000

Formation	Description of core	Depth (m)	Rock structures / soil description
WHANGAMARINO FORMATION	FLUVIATILE EDGE OF LIGHT BLUE GREEN SANDY FINE TO MEDIUM GRAVELS.		wet-saturated; loose; massive, poorly sorted gravels - greywacke GM-GW
	OLIVE BROWN FINE TO MEDIUM SANDY SILT WITH SOME CLAY. (FLUVIATILE)	61	Fe cementation at base of unit Contact subhorizontal Woody fibrous carbonaceous fragments 1cm ø
		62	saturated; stiff-hard; massive CH
	LIGHT GREENISH BROWN FINE TO MEDIUM GRAVELS (FLUVIATILE)	63	saturated, loose; massive; gravels greywacke, subrounded 5-6mm ø GP
			graded bed of loose silty fine sand. gravels with sandy silt matrix GM
	LIGHT OLIVE BROWN SANDY SILT WITH SOME GRANULES. (FLUVIATILE)	64	saturated; stiff; finely layered; bedding defined by carbonaceous material. ML-SM
	LIGHT GREEN BLUE SILTY/SANDY MEDIUM GRAVEL (FLUVIATILE)		saturated; loose; massive; greywacke gravels GM
	LIGHT GREY BROWN SILTY FINE SAND WITH SOME FINE-MEDIUM GRAVEL AND CLAY.	65	carbonaceous fragments common saturated; firm; massive; SM
WAIKATO COAL MEASURES	DARK OLIVE BROWN CARBONACEOUS MUDSTONE	66	Mottled light yellow brown, rare rootlets light whitish brown
		67	Dark olive brown, finely layered strong to very strong
			END OF BOREHOLE
		68	
		69	
		70	
		61	

Water pressure tests: Drilling difficult water pressure up to 700 psi. previously 100-200 psi

DRILLER: T. BROWN
STARTED: 8.1.85
FINISHED: 14.1.85
DRILL: FAILING 1250

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms) 100 50 10 5 1 0.1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION
Zones with core loss interpreted from geophysical logs
60.00-67.20 Cored (150mm ø)

LOGGED: P. KELSEY | DATE: 8.1.85 | TRACED: | CHECKED: P. KELSEY | VERTICAL SCALE: | SHEET 5 OF 6

PROJECT: | HOLE NO: 6651 | LENGTH: 67.25 | CORE BOXES: | DRG NO.

BQ 3/25 M

LOG OF DRILL HOLE

PROJECT: Huntly Subsidence | FEATURE: NZED Hostel | LOCATION: Rosser Street | HOLE NO. 6652

GRID REF: 675 930·26 535 339·26 | M.W.D. CO-ORD. | DATUM: Geodetic

ANGLE FROM HORIZONTAL: 090° | DIRECTION | H.A.D. GROUND: 12·04

PHOTO NO. | H.A.D. COLLAR

FORMATION NAME	DESCRIPTION OF CORE (grain size, texture, mineral content, hardness, strength, cement & matrix colour)	DEPTH H.A.D (m)	ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES; FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc)
Fill	Organic topsoil	0	
Fill	Fireclay fill: dark brown clayey gravel.		indurated mudstone fragments in a clay matrix GC
Fill	Light greyish yellow pumiceous medium to coarse sand with minor fine gravel. (Fill)	1–2	pumice dominant plus quartz, feldspar fragments subrounded SW-SP
Fill	Light brownish grey pumiceous fine sand		well sorted SP
Hinuera Formation	Light yellowish grey pumiceous medium to coarse sandy silt	3	MH
Hinuera Formation	Light yellowish brown clayey silt		ML
Hinuera Formation	Light brownish grey pumiceous silty medium to coarse sand	4–5	pumice and rhyolite fragments SM-SC
Hinuera Formation	Light yellowish brown pumiceous medium to coarse sandy silt	5–7	MH-SC; transitional boundary
Hamilton Ash	Light greyish yellow medium to coarse sandy fine gravels	7	rhyolite, pumice and andesite fragments GP
Kauroa-Hamilton Ash	Ignimbritic. Light yellowish grey pumiceous medium to coarse sandy silt	8–9	MH
Karapiro Formation	Light yellowish grey pumiceous silty medium to coarse sand with minor fine gravel.	9–10	SC; transitional boundary
Karapiro Formation	Light olive grey pumiceous fine sandy silt	11	MH
Karapiro Formation	Light yellowish brown medium to coarse sand with minor silt	12	SP
Karapiro Formation	Light olive grey pumiceous fine sandy silt with minor clay	13	MH-SC
Karapiro Formation	Black clayey peat with minor fine pumice gravel	14	Pt
			SP

DRILLER: T Brown

STARTED: 21·1·85

FINISHED: 23·1·85

DRILL: Failing 1250

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms): 100 50 10 5 0·1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION

0-15·00 Wash Drilled

LOGGED: P Kelsey | PROJECT:

DATE: | HOLE NO: 6652

TRACED: | LENGTH: 55·75 m

CHECKED: P Kelsey | CORE BOXES:

VERTICAL SCALE: 1:50

SHEET 1 OF 5 | DRG NO

LOG OF DRILL HOLE

PROJECT	Huntly Subsidence
FEATURE	NZED Hostel
HOLE NO.	6652
GRID REF.	625 930·26 335 339·26
M.W.D. CO-ORD.	
LOCATION	Rosser Street
ANGLE FROM HORIZONTAL	090°
DIRECTION	
DATUM	Geodetic
H.A.D. GROUND	12.04
PHOTO NO.	
H.A.D. COLLAR	

Column headings: DESCRIPTION OF CORE (FORMATION NAME; ROCK OR SOIL TYPE; DESCRIPTION OF CORE: (grain size, texture, mineral content, hardness, strength, cement & matrix colour)) | WEATHERING (SW MW HW) | HARDNESS (H MH MS S) | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % (5 10 50) | DEPTH H.A.D (Core size, casing) m | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms) | ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES: FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.) | DATE/DEPTH | R.Q.D. % | WATER LEVEL (Date) | DRILL WATER LOSS % (0-100) | WATER PRESSURE TESTS Permeability - LUGEONS (.01 .1 1 10 100 1000)

Formation	Description of core	Depth (m)	Rock structures / soil description
KARAPIRO FORMATION	LIGHT YELLOWISH GREY PUMICEOUS MEDIUM TO COARSE SAND WITH MINOR FINE GRAVEL	15–17.5	pumice dominant, quartz and feldspar SP
	LIGHT OLIVE YELLOW PUMICEOUS SILTY FINE SAND	17.5–19.4	SP
			dark green cemented (Fe?) band 1cm thick.
	PUMICEOUS FINE SAND	19.4–19.7	saturated; compact; finely layered; bedding sub horizontal. SP
	BANDED GREEN BROWN-LIGHT OLIVE BROWN CLAYEY SILT	19.7–20.0	saturated; v stiff - hard; coarsely layered;
	PALEOSOL DARK BROWN PEATY SILT	20.0–20.1	saturated, firm, Pt
	BLUE GREEN CLAYEY SILT	20.1–24.0	wet; stiff; massive; CL
WHANGAMARINO FORMATION	SANDY SILT	24.0–24.2	
	LIGHT BLUE-GREEN CLAYEY SILT	24.2–24.8	CL
	LIGHT YELLOWISH GREEN SILTY MEDIUM TO COARSE SAND	24.8–27.0	pumice and rhyolite fragments SM-SC
	DARK BLUISH GREEN PUMICEOUS MEDIUM TO COARSE SAND WITH MINOR FINE GRAVEL	27.0–30.0	pumice and rhyolite fragments SW

DRILLER:	T. Brown
STARTED:	21.1.85
FINISHED:	23.1.85
DRILL:	Failing 1250

WEATHERING: UW - Unweathered; SW - Slightly weathered; MW - Moderately weathered; HW - Highly weathered; CW - Completely weathered

HARDNESS: VH - Very hard; H - Hard; MH - Moderately hard; MS - Moderately soft; S - Soft; VS - Very soft

FRACTURE LOG (cms) 100 50 10 5 1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION
1500 - 19·48 Wash Drilled
1948 - 2189 Cored
2189 - 2958 Wash Drilled
2958 - 3000 Cored

LOGGED:	P. Kelsey
DATE:	
TRACED:	
CHECKED:	P. Kelsey
VERTICAL SCALE:	1:50
SHEET	2 OF 5
PROJECT:	
HOLE NO:	6652
LENGTH:	55.75
CORE BOXES:	
DRG NO	

LOG OF DRILL HOLE

HOLE NO. 6652

PROJECT: Huntly Subsidence — FEATURE: NZED Hostel — LOCATION: Rosser Street

GRID REF. 675 930 ·26 335 339·26 — M.W.D. CO-ORD. — DATUM: Geodetic — H.A.D. GROUND: 12.04

ANGLE FROM HORIZONTAL: 090° — DIRECTION — PHOTO NO. — H.A.D. COLLAR

DESCRIPTION OF CORE (Formation name; Rock or soil type; Description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	DEPTH H.A.D.	ROCK STRUCTURES (Defects) Joints, veins, seams, shatter, shear & crush zones; foliation, schistosity (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc)	DATE/DEPTH	R.Q.D. %
LIGHT GREEN GREY PUMICEOUS MEDIUM TO COARSE SAND		saturated, compact; massive; pumice granules up to 1cm ø, SW		
		dark green Fe(?) cemented base		
LIGHT BLUE GREEN CLAYEY SILT		2cm crush zone clayey silt + sand.		
	31	moist to wet; firm to hard; massive; CL		
	32			
	33			
	34	gradational boundary		
LIGHT BLUE GREEN / YELLOW BROWN SILTY MEDIUM TO COARSE SAND	35			
	36			
LIGHT BLUE GREEN CLAYEY SILT	37			
	38			
		5cm bed silty medium sand (quartz-feldspar) bedding 10°		
LIGHT BLUE GREEN SANDY SILT WITH SOME CLAY	39	wet; v. stiff to hard; massive; mottled;		
		carbonaceous sticks and rootlets		
INTERBEDDED LIGHT YELLOW GREEN SILTY MEDIUM TO COARSE SAND AND LIGHT BLUE GREEN SANDY FINE TO MEDIUM GRAVELS	40	gradational boundary		
		wet; compact; coarsely layered SM-SC		
	41	fibrous woody fragments.		
		saturated; compact; massive - coarsely layered at top; Tauranga Group gravels GM		
FINE SANDY SILT	42	wet; hard; massive; irregular dark vienlets ~SM		
SANDY FINE TO MEDIUM GRAVELS		Peat horizon.		
		rare coal fragments		
LIGHT BLUE GREEN CLAYEY SILT	43	wet; very stiff; massive,		
LIGHT GREEN GREY SILTY FINE TO MEDIUM SAND		transitional boundary		
		wet; compact; finely layered; carbonaceous material // to bedding, bedding subhorizontal SM		
INTERBEDDED DARK BROWN CLAYEY SILT AND SILTY MEDIUM SAND	44	fine to medium gravels described above		
		carbonaceous wood		
		saturated; loose; finely layered, bedding = SM	30-45°	
FINE TO MEDIUM GRAVELS		saturated, loose; massive; gravels greywacke plus Tauranga Group, minor coal GP		

FORMATION NAME: WHANGAMARINO FORMATION

Column headings also printed: WEATHERING (SW, MW, HW) — HARDNESS (H, MH, MS, S) — POINT LOAD TEST (kPa) — CORE LOSS/LIFT % (10, 50) — Core size, casing — GRAPHIC LOG — FRACTURE LOG (Spacing of natural fractures) (50, 10, 5 cms) — WATER LEVEL (Date) — DRILL WATER LOSS % (0-100) — WATER PRESSURE TESTS Permeability – LUGEONS (0.1, 1, 10, 100, 1000)

WEATHERING
UW – Unweathered
SW – Slightly weathered
MW – Moderately weathered
HW – Highly weathered
CW – Completely weathered

HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very soft

FRACTURE LOG (cms): Spacing of natural fractures (100, 50, 10, 5, 1, 0.1) / Fractures/m of core (1, 2, 10, 20, 100, 1000)

DRILLER: T. Brown
STARTED: 21.1.85
FINISHED: 23.1.85
DRILL: Failing 1250

EXPLANATION
30·00 – 31·61 Cored
31·61 – 38·76 Wash Drilled
38·76 – 44·77 Cored
44·77 – 55·00 Wash Drilled

LOGGED: P. Kelsey — PROJECT:
DATE: — HOLE NO: 6652
TRACED: — LENGTH: 55.75
CHECKED: P. Kelsey — CORE BOXES:
VERTICAL SCALE: 1:50
SHEET 3 OF 5 — DRG NO.

LOG OF DRILL HOLE

HOLE NO. 6652

PROJECT: Huntly Subsidence FEATURE: NZED Hostel LOCATION: Rosser Street

GRID REF: 625 930·26 335 339·26 M.W.D. CO-ORD. DATUM: Geodetic H.A.D. GROUND: 12·04

ANGLE FROM HORIZONTAL: 090° DIRECTION PHOTO NO. H.A.D. COLLAR

DESCRIPTION OF CORE (Formation name; Rock or soil type; Description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	Depth H.A.D. (m)	Rock structures (Defects) / (Or soil description)
WHANGAMARINO FORMATION — LIGHT GREYISH BROWN PUMICEOUS SILTY MEDIUM TO COARSE SAND		fragments of pumice, greywacke, rhyolite SM-SC
LIGHT YELLOWISH BROWN PUMICEOUS CLAYEY SILT	46	ML
LIGHT GREYISH BROWN SANDY FINE GRAVELS	47	GM
LIGHT BLUE GREY SILTY MEDIUM TO COARSE SAND	48	SM-SC
OLIVE WHITE PUMICEOUS CLAYEY SILT (LOWER IGNIMBRITIC SILT UNIT)	49–52	MH "soft drilling"
DARK GREEN MEDIUM TO COARSE SAND	52	SW
LIGHT YELLOWISH GREY SILTY CLAY	53	
WAIKATO COAL MEASURES — DARK OLIVE BROWN CARBONACEOUS MUDSTONE	53–55.75	
	56	END OF BOREHOLE

Column headings: WEATHERING (SW MW HW); HARDNESS (H MH MS S); POINT LOAD TEST (kPa); CORE LOSS/LIFT; DEPTH H.A.D.; Core size, casing; GRAPHIC LOG; FRACTURE LOG (Spacing of natural fractures) 50 10 5 cms; ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc); DATE/DEPTH; R.Q.D.; WATER LEVEL Date; DRILL WATER LOSS 0–100; WATER PRESSURE TESTS Permeability – LUGEONS 1 10 100 1000

DRILLER: T. Brown
STARTED: 2/1/85
FINISHED: 23/1/85
DRILL: Failing

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms): 100 50 10 5 1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION
4500–4507 Cored
4507–5575 Wash Drilled

LOGGED: P. Kelsey
DATE:
TRACED:
CHECKED: P. Kelsey
VERTICAL SCALE: 1:50
PROJECT:
HOLE NO: 6652
LENGTH: 55.75
CORE BOXES:
SHEET 4 OF 5 DRG NO

EQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6653

PROJECT *Huntly Subsidence* FEATURE *N.Z.E.D. Hostel* LOCATION *Reserve East of Rosser St*

GRID REF. *625 936.00 335 473.30* M.W.D. CO-ORD. .... DATUM *Geodetic*

ANGLE FROM HORIZONTAL *090°* DIRECTION .... H.A.D. GROUND *16.99*

PHOTO NO. .... H.A.D. COLLAR ....

DESCRIPTION OF CORE (FORMATION NAME: / ROCK OR SOIL TYPE: / DESCRIPTION OF CORE: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	WEATHERING (SW MW HW)	HARDNESS (H MH MS S)	POINT LOAD TEST (kPa)	CORE LOSS/LIFT % (5 10 50)	DEPTH H.A.D. Core size, casing (m)	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms)	ROCK STRUCTURES (Defects) JOINTS, VEINS: SEAMS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.)	DATE/DEPTH	R.Q.D. %	WATER LEVEL Date	DRILL WATER LOSS % 0-100	WATER PRESSURE TESTS Permeability - LUGEONS (.01 .1 1 10 100 1000)
KAUROA - HAMILTON ASHES: ORGANIC TOPSOIL: LIGHT BROWNISH GREY CLAYEY SILT WITH SOME MEDIUM SAND													
LIGHT YELLOWISH BROWN PUMICEOUS FINE TO MEDIUM SANDY SILT WITH SOME CLAY					1, 2, 3			MH					
WHITISH YELLOW PUMICEOUS CLAYEY SILT WITH SOME MEDIUM SAND					4			sand fraction: pumice, rhyolite (?)					
KARAPIRO FORMATION: BLACK FIBROUS SILTY PEAT					5			Pt			16.1.85		
FLUVIATILE LIGHT OLIVE GREY SILTY MEDIUM TO COARSE SAND WITH SOME FINE GRAVELS					6, 7			quartz, feldspar, pumice sand, pumice dominant larger clasts, quartz-feldspar dominant smaller SM			17.1.85		
GREY YELLOWISH BROWN COARSE SAND					8, 9			quartz, feldspar, greywacke, rhyolite and obsidian fragments. SW					
FLUVIATILE DARK BROWNISH GREY MEDIUM GRAVELS					10, 11			transitional boundary; greywacke clasts GP					
IGNIMBRITIC LIGHT YELLOW GREY PUMICEOUS SILTY FINE SAND					12, 13, 14			SM					

DRILLER: *T. Brown*

STARTED: *16.1.85*

FINISHED: *18.1.85*

DRILL: *Failing 1250*

WEATHERING
UW – Unweathered
SW – Slightly weathered
MW – Moderately weathered
HW – Highly weathered
CW – Completely weathered

HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very soft

FRACTURE LOG (cms) 100 50 10 5 1 .01 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION
0-10.03 Wash Drilled
10.03-13.20 Cored (150mm ⌀)
13.20-14.60 Wash Drilled
14.60-15.00 Cored (150mm ⌀)

LOGGED: *P. Kelsey* PROJECT: ....
DATE: *16-18.1.85* HOLE NO: *6653*
TRACED: .... LENGTH: *61.60*
CHECKED: *P. Kelsey* CORE BOXES: ....
VERTICAL SCALE: *1:50*
SHEET ....OF.... DRG NO ....

LOG OF DRILL HOLE

HOLE NO. 6653

PROJECT: HUNTLY SUBSIDENCE FEATURE: N.Z.E.D. HOSTEL LOCATION: RESERVE EAST OF ROSSER STREET

GRID REF.: 625 936.00 335 427.30 M.W.D. CO-ORD.: DATUM: GEODETIC H.A.D. GROUND: 16.99

ANGLE FROM HORIZONTAL: 090° DIRECTION: PHOTO NO.: H.A.D. COLLAR:

Depth H.A.D. (m)	DESCRIPTION OF CORE (Formation name; rock or soil type; description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	ROCK STRUCTURES (Defects): joints, veins, seams, shatter, shear & crush zones, foliation, schistosity (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc)
15–17	IGNIMBRITIC LIGHT YELLOW GREY PUMICEOUS SILTY FINE SAND	bedding 0-20° mm scale; saturated, loose; massive; dilatant SP rare carbonaceous fragments
17–17.8	INTERBEDDED CLAY, FINE SAND, CLAYEY SILT AND MEDIUM TO COARSE SAND	saturated; stiff; finely layered MH bedding 5-10°; saturated; stiff; massive; MH
17.8–19.6	LIGHT YELLOW BROWN PUMICEOUS MEDIUM TO COARSE SAND WITH SOME FINE GRAVELS	saturated; loose; massive; SW; transitional boundary
19.6–20.9	LIGHT YELLOW BROWN PUMICEOUS FINE SAND	saturated; loose; coarsely layered; dilatant SP
20.9–21.3	DARK BROWN AND LIGHT YELLOWISH GREY CLAYEY SILT	saturated; firm to stiff; finely layered - bedding subhorizontal
21.3–21.6	SILTY FINE SAND	saturated; loose, finely layered SM
21.6–24	LIGHT YELLOW GREY PUMICEOUS COARSE SAND WITH SOME FINE GRAVEL	finely bedded - subhorizontal; saturated; moderately compact; SP; massive; Fe oxide "hardpan" - (siderite?)
24–24.3	YELLOW BROWN CLAYEY SILT	saturated; hard; bedding on cm scale
24.3–24.6	PALEOSOLS: DARK BROWN CARBONACEOUS CLAYEY SILT	Pt; carbonaceous fragments
24.6–27.2	LIGHT BLUE GREEN CLAYEY SILT	moist - saturated; stiff to hard; massive; CL
27.2–28.1	LIGHT GREYISH GREEN SILTY SAND	SM
28.1–30	LIGHT GREYISH GREEN CLAYEY SILT	CL

Formations: KARAPIRO FORMATION (approx. 15–24.3 m); WHANGAMARINO FORMATION (approx. 24.3–30 m)

Depth scale: 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29

Column headings: SW MW HW WEATHERING; H MH MS S HARDNESS; POINT LOAD TEST (kPa); CORE LOSS/LIFT % (5 10 50); DEPTH H.A.D. Core size, casing (m); GRAPHIC LOG; FRACTURE LOG (Spacing of natural fractures) 50 10 5 cms; DATE/DEPTH; R.Q.D. %; WATER LEVEL (Date); DRILL WATER LOSS % (0-100); WATER PRESSURE TESTS Permeability – LUGEONS (·01 ·1 1 10 100 1000)

DRILLER: T. BROWN

STARTED: 16.1.85

FINISHED: 18.1.85

DRILL: FAILING 1250

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG: (cms) 100 50 10 5 1; Spacing of natural fractures; 1 2 10 20 100 1000 Fractures/m of core

EXPLANATION

15.00-15.28 Cored (150mm ø)

25.28-30.00 Wash Drilled

LOGGED: P. KELSEY	PROJECT:		
DATE: 16-18.1.85	HOLE NO: 6653		
TRACED:	LENGTH: 61.60		
CHECKED: P. KELSEY	CORE BOXES:		
VERTICAL SCALE: 1:50			
SHEET 2 OF 6	DRG NO		

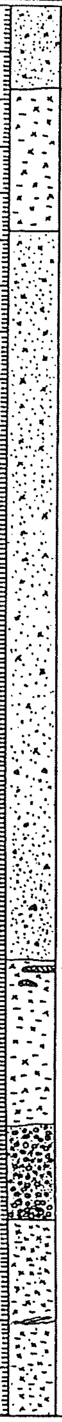
EQ 3/25 M

LOG OF DRILL HOLE

HOLE NO.	6653
PROJECT	HUNTLY SUBSIDENCE
FEATURE	N.Z.E.D. HOSTEL
LOCATION	RESERVE EAST OF ROSSER ST
GRID REF	125936.00 335623.30
M.W.D. CO-ORD	
DATUM	GEODETIC
H.A.D. GROUND	16.99
ANGLE FROM HORIZONTAL	090°
DIRECTION	
PHOTO NO.	
H.A.D. COLLAR	

Column headings: DESCRIPTION OF CORE — FORMATION NAME: / ROCK OR SOIL TYPE: / DESCRIPTION OF CORE: (grain size, texture, mineral content, hardness, strength, cement & matrix colour). | WEATHERING (SW MW HW) | HARDNESS (H MH MS S) | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % (5 10 50) | DEPTH H.A.D (Core size, casing; m) | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms) | ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES; FOLIATION; SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.) | DATE/DEPTH | R.Q.D. % | WATER LEVEL (Date) | DRILL WATER LOSS % (0-100) | WATER PRESSURE TESTS Permeability – LUGEONS (.01 .1 1 10 100 1000)

Formation name: WHANGAMARINO FORMATION



Depth (m)	Description of core	Rock structures / soil description
to ~30.8	GREYISH GREEN SILTY SAND	SM
~30.8 – ~32.4	DARK BROWN AND GREYISH GREEN CLAYEY SILT	ML
~32.4 – ~38.5	IGNIMBRITIC SILTY SAND	SM; transitional boundary
~38.5 – ~40.2	LIGHT GREY GREEN MEDIUM TO COARSE SAND WITH SOME FINE GRAVEL	saturated; compact; quartz, feldspar, greywacke and minor pumice SW
~40.2 – ~42.0	LIGHT BROWNISH YELLOW AND LIGHT GREENISH GREY CLAYEY SILT (FLUVIATILE)	fibrous organic fragments 5-10cm long; moist to saturated; hard; massive
~42.0 – ~43.0	LIGHT GREENISH GREY SANDY FINE GRAVELS WITH SOME SILT	saturated; compactness variable; gravels at base without fines
~43.0 –	LIGHT GREEN GREY CLAY SILT WITH SOME FINE SAND.	wet to saturated; stiff to hard; massive ML; organic rich layer (44)

Depth marks: 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44

DRILLER: T. BROWN	WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered	HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft	FRACTURE LOG (cms) Spacing of natural fractures: 100 50 10 5 1 .01; Fractures/m of core: 1 2 10 20 100 1000	LOGGED: P. KELSEY	PROJECT:
STARTED: 16.1.85				DATE: 16-18.1.85	HOLE NO: 6653
FINISHED: 18.1.85	EXPLANATION			TRACED:	LENGTH: 61.60
DRILL: FAILING 1250	30.00 – 39.75 Wash drilled			CHECKED: P. KELSEY	CORE BOXES:
	39.75 – 45.00 Cored (150mm ø)			VERTICAL SCALE: 1:50	
				SHEET 3 OF 5	DRG NO

BQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6653

PROJECT: HUNTLY SUBSIDENCE
FEATURE: N.Z.E.D. HOSTEL
LOCATION: RESERVE EAST OF ROSSER ST
GRID REF.: 625 936.00 335 623.30
M.W.D. CO-ORD.:
DATUM: GEODETIC
H.A.D. GROUND: 16.99
ANGLE FROM HORIZONTAL: 090°
DIRECTION:
PHOTO NO.:
H.A.D. COLLAR:

Column headings: DESCRIPTION OF CORE — FORMATION NAME: ROCK OR SOIL TYPE: DESCRIPTION OF CORE: (grain size, texture, mineral content, hardness, strength, cement & matrix colour). | WEATHERING (SW MW HW) | HARDNESS (H MH MS S) | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % (5 10 50) | DEPTH H.A.D. (Core size, casing, m) | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms) | ROCK STRUCTURES (Defects) JOINTS: VEINS. SEAMS. SHATTER, SHEAR & CRUSH ZONES: FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc) | DATE/DEPTH | R.Q.D. % | WATER LEVEL (Date) | DRILL WATER LOSS % (0–100) | WATER PRESSURE TESTS Permeability – LUGEONS (.01 .1 1 10 100 1000)

Formation: WHANGAMARINO FORMATION

Depth marks: 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59

Description of core

- MOTTLED DARK BLUE GREEN AND LIGHT BLUE GREEN MEDIUM SAND WITH SOME FINE GRAVEL
- IGNIMBRITIC SILT UNIT / LOWER:
  - IGNIMBRITIC
    LIGHT GREENISH GREY CLAYEY SILT WITH RARE INTERBEDS OF FINE SAND
  - IGNIMBRITIC
    LIGHT GREENISH GREY FINE TO MEDIUM SANDY SILT WITH SOME FINE GRAVELS
  - LIGHT GREEN GREENISH GREY SILTY MEDIUM SAND
- IGNIMBRITIC
  LIGHT GREY MEDIUM SAND WITH SOME FINE GRAVEL
- LIGHT AND DARK BLUISH GREEN MEDIUM GRAVELLY MEDIUM SAND WITH SOME SILT
- FLUVIATILE
  LIGHT GREENISH GREY CLAYEY SILT
- LIGHT GREENISH GREY FINE SANDY SILT
- LIGHT GREENISH GREY SANDY MEDIUM GRAVELS WITH SOME SILT
- FLUVIATILE
  LIGHT GREENISH BROWN MEDIUM TO COARSE SAND WITH SOME SILT
- LIGHT GREYISH GREEN CLAYEY SILT
- LIGHT GREENISH GREY SANDY MEDIUM GRAVELS WITH SOME SILT (FLUVIATILE)
- DARK BROWN CARBONACEOUS CLAYEY SILT (FLUVIATILE)
- LIGHT GREENISH GREY SILTY MEDIUM GRAVELS (FLUVIATILE)

Rock structures (soil description)

- contact 30°
- moist; compact (cemented); bedded (cm) SP
- wet; hard; massive, MH
- interbeds graded (bedding) fine sand
- rare fine gravel
- transitional
- drilling induced fractures (core barrel over loaded)
- saturated; stiff to hard; massive gravels rhyolite ?
- saturated; compact; massive SM
- interbedded black clayey silt.
- transitional
- saturated; compact; massive; SP rare greywacke gravel
- Pt
- saturated; compact; massive SP-GP
- top subhorizontal, dark brown organic fragments
- saturated; stiff to hard; massive MH
- joint // borehole walls; planar rough surface
- transitional
- saturated; variable compactness, massive; gravels-greywacke subrounded and subangular SW-GP
- wood fragment - 6cm long, 4cm ø
- saturated; loose; massive SW.
- saturated; soft; massive MH
- < 6cm thick sand lenses
- GP
- wet; stiff, finely bedded; Pt
- saturated; loose; massive GM

DRILLER: T BROWN	WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered	HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft	FRACTURE LOG (cms) 100 50 10 5 1 — Spacing of natural fractures / Fractures/m of core 1 2 10 20 100
STARTED: 11.1.85	EXPLANATION: 45.00-60.00 Cored (150mm ø)		LOGGED: P KELSEY; DATE: 16.18.1.85; TRACED: ; CHECKED: P KELSEY; VERTICAL SCALE: 1:50
FINISHED: 18.1.85			PROJECT: ; HOLE NO: 6653; LENGTH: 61.60; CORE BOXES:
DRILL: FAILING 1250			SHEET 4 OF 6; DRG NO

EQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6653

PROJECT Huntly Subsidence FEATURE NZED Hostel LOCATION Reserve East of Rosser St
GRID REF. 625 936.00 335 623.30 M.W.D. CO-ORD. DATUM Geodetic
ANGLE FROM HORIZONTAL 090° DIRECTION PHOTO NO. H.A.D. GROUND 16.99 H.A.D. COLLAR

DESCRIPTION OF CORE (Formation name; Rock or soil type; Description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	Depth H.A.D.	Rock Structures (Defects) (or Soil Description)
GREENISH WHITE CLAYEY SILT (FLUVIATILE)		saturated, "compact", fragments of Tauranga Group stiff clayey silt in a silty matrix
GREEN MEDIUM SILTY GRAVEL		
LIGHT BROWN/GREYISH GREEN CLAYEY SILT		Note: Contact with no weathering zone
DARK GREYISH BROWN CARBONACEOUS MUDSTONE	61	— finely layered (laminated)
	62	END OF BOREHOLE
	63	

Formation: WAIKATO COAL MEASURES

DRILLER: T. BROWN
STARTED: 16.1.85
FINISHED: 18.1.85
DRILL: FAILING 1250

WEATHERING
UW – Unweathered
SW – Slightly weathered
MW – Moderately weathered
HW – Highly weathered
CW – Completely weathered

HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very soft

FRACTURE LOG
(cms) Spacing of natural fractures
Fractures/m of core

EXPLANATION

LOGGED: P. KELSEY
DATE: 16-18.1.85
TRACED:
CHECKED: P. KELSEY
VERTICAL SCALE: 1:50
PROJECT:
HOLE NO: 6653
LENGTH: 61.60
CORE BOXES:
SHEET 5 OF 6 DRG NO

LOG OF DRILL HOLE

HOLE NO. 6654

PROJECT: HUNTLY SUBSIDENCE
FEATURE: NZEO HOSTEL
LOCATION: BURKE PLACE
GRID REF: 625 981.85 N 335 638.83 E
M.W.D. CO-ORD.
DATUM: GEODETIC
ANGLE FROM HORIZONTAL: 090°
DIRECTION
H.A.D. GROUND: 41.59
PHOTO NO.
H.A.D. COLLAR

DESCRIPTION OF CORE
FORMATION NAME:
ROCK OR SOIL TYPE:
DESCRIPTION OF CORE: (grain size, texture, mineral content, hardness, strength, cement & matrix colour).

Column headings: WEATHERING (SW MW HW) | HARDNESS (H MH MS S) | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % (50 50) | DEPTH H.A.D (Core size, casing) | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms) | ROCK STRUCTURES (Defects) JOINTS VEINS. SEAMS. SHATTER, SHEAR & CRUSH ZONES. FOLIATION: SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc) | DATE/DEPTH | R.Q.D. % | WATER LEVEL (Date) | DRILL WATER LOSS % (0-100) | WATER PRESSURE TESTS Permeability - LUGEONS (.01 .1 1 10 100 1000)

Formation	Description of core	Depth (m)	Rock structures / soil description
KAUROA - HAMILTON ASHES	TOPSOIL: MOTTLED DARK YELLOWISH BROWN PEATY SILT WITH SOME SAND	0	
	LIGHT YELLOWISH BROWN SILTY COARSE SAND WITH SOME CLAY AND FINE GRAVELS.	1	quartz-feldspar-pumice sand with minor greywacke SM
IGNIMBRITIC SILT UNIT	LIGHT REDDISH BROWN PUMICEOUS CLAYEY SILT WITH SOME COARSE SAND (IGNIMBRITIC)	2–5	ML-MH
	MOTTLED RED AND CREAM CLAYEY SILT	5–7	transitional boundary
	LIGHT YELLOWISH GREY PUMICEOUS COARSE SAND WITH SOME SILT	7–8	rare obsidian, SP
UPPER	MOTTLED RED AND WHITE HALLOYSITIC SILTY CLAY (IGNIMBRITIC)	8–9	
	WHITISH YELLOW PUMICEOUS SILTY MEDIUM TO COARSE SAND	9–10	transitional boundary
KARAPIRO FORMATION	LIGHT BROWNISH GREY MEDIUM TO COARSE SAND	10–11	quartz-feldspar-greywacke sand SP
	LIGHT YELLOWISH BROWN SANDY FINE GRAVELS WITH SOME SILT	11–13	greywacke dominant GP
	YELLOWISH BROWN MEDIUM TO COARSE SAND WITH SOME FINE GRAVELS.	13–15	greywacke, quartz, feldspar dominant SW-SP

Depth column annotation: 100mm casing to 8.00 (approx.)

DRILLER: G. LEWER
STARTED: 17.12.84
FINISHED: 20.12.84
DRILL: GARDNER DENVER 200T

WEATHERING
UW - Unweathered
SW - Slightly weathered
MW - Moderately weathered
HW - Highly weathered
CW - Completely weathered

HARDNESS
VH - Very hard
H - Hard
MH - Moderately hard
MS - Moderately soft
S - Soft
VS - Very soft

FRACTURE LOG (cms): 100 50 10 5 1 .5 .1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION
0-15.00 Wash Drilled.

LOGGED: P. KELSEY
DATE: 27.8.85
TRACED:
CHECKED: P. KELSEY
VERTICAL SCALE: 1:50
PROJECT:
HOLE NO: 6654
LENGTH: 67.95 m
CORE BOXES:
SHEET 1 OF 6
DRG NO

LOG OF DRILL HOLE

HOLE NO. 6654

PROJECT *Huntly Subsidence* FEATURE *NZED Hostel* LOCATION *Burke Place*

GRID REF. *675 981·85N 335 638·83E* M.W.D. CO-ORD. DATUM *Geodetic*

ANGLE FROM HORIZONTAL *090°* DIRECTION PHOTO NO. H.A.D. GROUND *41·59*

H.A.D. COLLAR

DESCRIPTION OF CORE
FORMATION NAME:
ROCK OR SOIL TYPE:
DESCRIPTION OF CORE: (grain size, texture, mineral content, hardness, strength, cement & matrix colour).

WEATHERING (SW MW HW) | HARDNESS (H MH MS S) | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % (5 10 50) | DEPTH HAD (Core size, casing) | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms) | ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.) | DATE/DEPTH | R.Q.D. % | WATER LEVEL (Date) | DRILL WATER LOSS % (0–100) | WATER PRESSURE TESTS Permeability – LUGEONS (.01 .1 1 10 100 1000)

Formation: *KARAPIRO FORMATION*

Depth (m)	Description of core	Rock structures (or soil description)
to ~19.0	*LIGHT YELLOWISH GREY MEDIUM TO COARSE SAND WITH SOME FINE GRAVEL.*	*quartz feldspar and greywacke dominant with minor pumice SW-SP*
~19.0 – ~23.1	*LIGHT GREYISH YELLOW PUMICEOUS MEDIUM TO COARSE SAND WITH SOME FINE GRAVEL AND SILT (IGNIMBRITIC ?)*	*pumice rich with quartz and feldspar SW-SP*
~23.1 – ~25.0	*LIGHT GREYISH YELLOW COARSE SAND (IGNIMBRITIC ?)*	*pumice, quartz-feldspar sand SP*
~25.0 – ~26.2	*LIGHT YELLOWISH BROWN MEDIUM TO COARSE SAND*	*SW-SP*
~26.2		*transitional boundary*
~26.2 – ~27.1	*LIGHT YELLOWISH BROWN COARSE SANDY FINE GRAVEL*	*GP*
~27.1 – 29.9	*LIGHT YELLOWISH BROWN FINE TO MEDIUM SAND WITH SOME SILT AND FINE GRAVEL*	*SW*

Depth scale: 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29

Water level: *17·12·84* (at ~16 m); *19·12·84* (at ~27.5 m)

DRILLER: *G. Lewer*
STARTED: *17.12.84*
FINISHED: *20.12.84*
DRILL: *Gardner-Denver 2007*

WEATHERING
UW – Unweathered
SW – Slightly weathered
MW – Moderately weathered
HW – Highly weathered
CW – Completely weathered

HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very soft

FRACTURE LOG (cms) 100 50 10 5 1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION
15·00–30·00 Wash Drilled

LOGGED: *P. Kelsey* PROJECT:
DATE: *27.8.85* HOLE NO: *6654*
TRACED: LENGTH: *67·95*
CHECKED: *P. Kelsey* CORE BOXES:
VERTICAL SCALE: *1:50*
SHEET *2* OF *6* DRG NO

NQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6654

PROJECT Huntly Subsidence FEATURE NZED Hostel LOCATION Burke Place
GRID REF. 625 981.85N 335 638.83E M.W.D. CO-ORD. DATUM Geodetic H.A.D. GROUND 41.59
ANGLE FROM HORIZONTAL 090° DIRECTION PHOTO NO. H.A.D. COLLAR

DESCRIPTION OF CORE (FORMATION NAME; ROCK OR SOIL TYPE; DESCRIPTION OF CORE: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	DEPTH H.A.D.	ROCK STRUCTURES (Defects) / (OR SOIL DESCRIPTION)
KARAPIRO FORMATION — LIGHT YELLOWISH BROWN FINE TO MEDIUM SAND WITH SOME SILT AND FINE GRAVEL.	30–35.5	quartz-feldspar, pumice sand SW
YELLOWISH WHITE PUMICEOUS SILTY FINE SAND WITH SOME FINE GRAVELS.	35.5–42.5	SC-SM
YELLOWISH WHITE PUMICEOUS SILTY FINE TO MEDIUM SAND	42.5–43	
GREYISH WHITE PUMICEOUS SILTY COARSE SAND	43–44	pumice rich with rare greywacke fragments; pumice rounded SM
GREYISH WHITE CLAYEY SILT WITH SOME COARSE SAND	44–45	

Depth markers: 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44
Core size annotations: 200mm casing; 38.1; 56.0mm

DRILLER: G. Lemer
STARTED: 17.12.84
FINISHED: 20.12.84
DRILL: Gardner Denver 200T

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms): Spacing of natural fractures; Fractures/m of core

EXPLANATION
30.00–45.00 Wash Drilled

LOGGED: P. Kelsey
DATE: 27.8.85
TRACED:
CHECKED: P. Kelsey
VERTICAL SCALE: 1:50
PROJECT:
HOLE NO: 6654
LENGTH: 67.95
CORE BOXES:
SHEET 3 OF 6 DRG NO

LOG OF DRILL HOLE

HOLE NO. 6654

PROJECT: Huntly Subsidence FEATURE: N.Z.E.D. Hostel LOCATION: Burke Place

GRID REF: 625 981.85N 335 638.83E M.W.D. CO-ORD. DATUM: Geodetic H.A.D. GROUND 41.59

ANGLE FROM HORIZONTAL: 090° DIRECTION PHOTO NO. H.A.D. COLLAR

DESCRIPTION OF CORE (Formation name; Rock or soil type; Description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	Depth H.A.D. (m)	ROCK STRUCTURES (Defects) / (OR SOIL DESCRIPTION)
KARAPIRO FORMATION: Greyish white clayey silt with some coarse sand	to 46	
Greyish white pumiceous silty coarse sand with some fine gravel	46–47.5	pumice, quartz, feldspar sand with rare greywacke fragments SC-SM
Brownish grey sandy silt	47.5–49.2	↑ transitional boundary; siderite hard pan
WHANGAMARINO FORMATION: Paleosol carbonaceous clayey silt	49.2–49.3	
Light blue grey clayey silt	49.3–52.2	
Light yellowish grey coarse sand with some fine gravel	52.2–54	greywacke dominant SP
Dark brown silty fine sand	54–56	SM
Light greyish brown fine gravels with some sand.	56–57.6	rhyolite, greywacke and obsidian (rare) fragments GP
Ignimbritic light greenish grey pumiceous medium to coarse sandy silt with some clay (Lower ignimbritic silt)	57.6–60	MH

Depth markings: 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59. Casing: 200mm; 150mm.

DRILLER: G. Lever	WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered
STARTED: 17.12.84	HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft
FINISHED: 20.12.84	FRACTURE LOG: Spacing of natural fractures (cms) / Fractures/m of core
DRILL: Gardner Denver 2007	EXPLANATION: 45.00–60.00 Wash Drilled

LOGGED: P.Kelsey DATE: 27.8.85 TRACED: CHECKED: P.Kelsey VERTICAL SCALE: 1:50

PROJECT: HOLE NO. 6654 LENGTH: 67.95 CORE BOXES:

SHEET 4 OF 6 DRG NO.

MQ 3/25 M

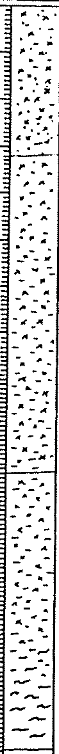
LOG OF DRILL HOLE

PROJECT: Huntly Subsidence | FEATURE: NZED Hostel | LOCATION: Burke Place | HOLE NO.: 6654

GRID REF: 675 981·85N 335 638·83E | M.W.D. CO-ORD.: | DATUM: Geodetic

ANGLE FROM HORIZONTAL: 090° | DIRECTION: | PHOTO NO.: | H.A.D. GROUND: 41·59 | H.A.D. COLLAR:

DESCRIPTION OF CORE (FORMATION NAME; ROCK OR SOIL TYPE; DESCRIPTION OF CORE: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	WEATHERING (SW MW HW)	HARDNESS (H MH MS S)	POINT LOAD TEST (kPa)	CORE LOSS/LIFT % (5 10 50)	DEPTH H.A.D. (Core size, casing)	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms)	ROCK STRUCTURES (Defects): JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES; FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.)	DATE/DEPTH	R.Q.D. %	WATER LEVEL (Date)	DRILL WATER LOSS % (0–100)	WATER PRESSURE TESTS Permeability – LUGEONS (·01 ·1 1 10 100 1000)
WHANGAMARINO FORMATION — LOWER IGNIMBRITIC SILT					61								
WHANGAMARINO FORMATION — LIGHT BROWNISH YELLOW SILTY CLAY					62, 63, 64			CH					
WAIKATO COAL MEASURES — LIGHT YELLOW BROWN AND REDDISH BROWN SILTY CLAY					65, 66			CH					
WAIKATO COAL MEASURES — DARK OLIVE BROWN CLAYEY SILTSTONE					67, 68			transitional boundary					
					69, 70								



DRILLER:	WEATHERING	HARDNESS	FRACTURE LOG (cms)
C. Lewer	UW – Unweathered	VH – Very hard	Spacing of natural fractures: 100 50 10 5 1 0·1
STARTED: 17.12.84	SW – Slightly weathered	H – Hard	Fractures/m of core: 1 2 10 20 100 1000
FINISHED: 20.12.84	MW – Moderately weathered	MH – Moderately hard	
DRILL: Gardner Denver 200T	HW – Highly weathered	MS – Moderately soft	
	CW – Completely weathered	S – Soft	
		VS – Very soft	

EXPLANATION

LOGGED: P. Kelsey	PROJECT:
DATE: 27.8.85	HOLE NO: 6654
TRACED:	LENGTH: 67·95
CHECKED: P. Kelsey	CORE BOXES:
VERTICAL SCALE: 1:50	
SHEET 5 OF 6	DRG NO

LOG OF DRILL HOLE

HOLE NO. 6655

PROJECT Huntly Subsidence FEATURE NZED Hostel LOCATION Hostel Grounds

GRID REF 626 063 13 mN 335 578 88 mE M.W.D. CO-ORD. DATUM Geodetic

ANGLE FROM HORIZONTAL .... DIRECTION .... H.A.D. GROUND 27.78

PHOTO NO. .... H.A.D. COLLAR ....

DESCRIPTION OF CORE (Formation name; Rock or soil type; Description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	Unit	Depth H.A.D. (m)	Rock structures (Defects) / (or soil description)
TOPSOIL DARK BROWN-GREY MOTTLED CLAYEY SILT WITH SOME FINE SAND	Kuroa - Hamilton Ashes	0	rootlets common
LIGHT YELLOW BROWN AND REDDISH BROWN SILTY CLAY WITH MINOR FINE SAND	Kuroa - Hamilton Ashes	~0.5–1	CL-CH
LIGHT REDDISH BROWN PUMICEOUS SILTY FINE TO MEDIUM SAND WITH MINOR CLAY	Kuroa - Hamilton Ashes; Ignimbritic Silt Unit	1–4	rock fragment dominated (pumice) minor quartz and feldspar SM
SILTY MEDIUM TO COARSE SAND	Kuroa - Hamilton Ashes; Ignimbritic Silt Unit	4–6	SM
YELLOWISH WHITE PUMICEOUS FINE TO MEDIUM SANDY SILT WITH SOME CLAY.	Kuroa - Hamilton Ashes; Upper	6–8	rock fragments - pumice silt and clay halloysitic
IGNIMBRITIC LIGHT GREYISH YELLOW PUMICEOUS FINE TO MEDIUM SAND WITH MINOR FINE GRAVEL	Karapiro Formation	8–15	pumice rich, minor rhyolite, quartz and feldspar. SP; minor Fe oxide staining (~11.5); minor silt (~14.2)

Core size, casing: 200mm casing to 8.00

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms): Spacing of natural fractures / Fractures/m of core

DRILLER: G. Lewer

STARTED: 14.12.84

FINISHED: 15.12.84

DRILL: Gardner Denver 2007

EXPLANATION
0-15.00 Wash Drilled

LOGGED: P. Kelsey | PROJECT: ....
DATE: 26.8.85 | HOLE NO: 6655
TRACED: .... | LENGTH: 58.90
CHECKED: P. Kelsey | CORE BOXES ....
VERTICAL SCALE: 1:50

SHEET 1 OF 5 DRG NO ....

HQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6655

PROJECT Huntly Subsidence FEATURE NZED Hostel LOCATION Hostel Grounds

GRID REF. 626 863.63 m N 335 578.88 m E M.W.D. CO-ORD. DATUM Geodetic

ANGLE FROM HORIZONTAL DIRECTION PHOTO NO. H.A.D. GROUND 27.78

H.A.D. COLLAR

DESCRIPTION OF CORE — FORMATION NAME: ROCK OR SOIL TYPE: DESCRIPTION OF CORE (grain size, texture, mineral content, hardness, strength, cement & matrix colour).

WEATHERING (SW MW HW) | HARDNESS (H MH MS S) | POINT LOAD TEST (kPa) | CORE LOSS/LIFT | DEPTH H.A.D. m | Core size, casing | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) 50 10 5 1 cms | ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc) | DATE/DEPTH | R.Q.D. | WATER LEVEL Date | DRILL WATER LOSS 0–100 | WATER PRESSURE TESTS Permeability - LUGEONS .01 .1 1 10 100 1000

KARAPIRO FORMATION

IGNIMBRITIC
LIGHT GREYISH YELLOW PUMICEOUS FINE TO MEDIUM SAND — pumice rich SP

Depth: 16, 17, 18 — minor fine gravels

19, 20 — transitional boundary

LIGHT YELLOWISH BROWN MEDIUM TO COARSE SAND WITH SOME FINE GRAVEL. — quartz, feldspar rich; minor pumice

21, 22, 23, 24, 25, 26, 27, 28, 29 — transitional boundary

DRILLER: GLENER
STARTED: 16.12.84
FINISHED: 15.12.84
DRILL: Gardner Denver 200T

WEATHERING: UW - Unweathered; SW - Slightly weathered; MW - Moderately weathered; HW - Highly weathered; CW - Completely weathered

HARDNESS: VH - Very hard; H - Hard; MH - Moderately hard; MS - Moderately soft; S - Soft; VS - Very soft

FRACTURE LOG (cms) 100 50 10 5 1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION
15.00-30.00 Wash Drilled

LOGGED: P.KELSEY PROJECT:
DATE: 26.8.85 HOLE NO: 6655
TRACED: LENGTH: 58.90
CHECKED: P.KELSEY CORE BOXES:
VERTICAL SCALE: 1:50
SHEET 2 OF 5 DRG NO

NQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6655

PROJECT: Huntly Subsidence FEATURE: N.Z.E.D. Hostel LOCATION: Hostel Grounds

GRID REF.: 6X 013 63.N 335 578.83-E M.W.D. CO-ORD.: DATUM: Geodetic

ANGLE FROM HORIZONTAL: DIRECTION: PHOTO NO.: H.A.D. GROUND: 27.78 H.A.D. COLLAR:

Formation	Description of core (formation name; rock or soil type; grain size, texture, mineral content, hardness, strength, cement & matrix colour)	Depth H.A.D (m)	Rock structures (defects) (or soil description)
Karapiro Formation	Light yellow brown coarse sandy fine gravels		greywacke gravels; fining upwards GM
Karapiro Formation	Yellowish white pumiceous clayey silt	31	
Karapiro Formation	Blue grey/light yellow brown fine gravels with some medium gravels and coarse sand	32	greywacke gravels GP
Karapiro Formation	White pumiceous clayey silt	33	
Karapiro Formation	Light yellowish brown pumiceous medium to coarse sand	34	pumice rich, minor greywacke and rhyolite fragments SP
	Paleosol: dark brown fibrous silty peat		Pt
Whangamarino Formation	Light blue green silty clay with some medium to coarse sand	35	CL
		36	sand rich horizon
Whangamarino Formation	Light blue green silty clay with some medium to coarse sand.	37–39	CL; drilling "soft" at base of unit.
Whangamarino Formation	Light grey green silty coarse sand	40	greywacke rich SM; transitional boundary
Whangamarino Formation	Light yellowish grey silty medium sand	41–42	greywacke-quartz-feldspar dominant SM
Whangamarino Formation	Bluish green coarse sandy fine gravels	43–44	transitional boundary; greywacke gravels, clasts subangular to subrounded. GM-GP
Whangamarino Formation	Light grey pumiceous clayey silt with minor fine sand (ignimbritic)		unit mottled at top.

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms): Spacing of natural fractures / Fractures/m of core

DRILLER: G. Lener
STARTED: 14.12.84
FINISHED: 15.12.84
DRILL: Gardner Denver 2007

EXPLANATION: 30.00–45.00 Wash Drilled

LOGGED: P. Kelsey PROJECT:
DATE: 26.8.85 HOLE NO.: 6655
TRACED: LENGTH: 58.90
CHECKED: P. Kelsey CORE BOXES:
VERTICAL SCALE: 1:50
SHEET 3 OF 5 DRG NO.

LOG OF DRILL HOLE

HOLE NO. 6655

PROJECT Huntly Subsidence FEATURE NZED Hostel LOCATION Hostel Grounds

GRID REF. (26 063.63mN 335578.88mE) M.W.D. CO-ORD. DATUM Geodetic

ANGLE FROM HORIZONTAL DIRECTION PHOTO NO. H.A.D. GROUND 27.78

H.A.D. COLLAR

DESCRIPTION OF CORE: FORMATION NAME: ROCK OR SOIL TYPE: DESCRIPTION OF CORE: (grain size, texture, mineral content, hardness, strength, cement & matrix colour). | WEATHERING SW MW HW | HARDNESS H MH MS S | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % | DEPTH H.A.D. Core size, casing | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) | ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES; FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc) | DATE/DEPTH | R.Q.D. % | WATER LEVEL | DRILL WATER LOSS % | WATER PRESSURE TESTS Permeability - LUGEONS

Formation	Unit	Description of core	Depth	Soil description
Whangamarino Formation	Lower Ignimbritic Silt Unit	IGNIMBRITIC GREYISH WHITE PUMICEOUS CLAYEY SILT WITH SOME MEDIUM TO COARSE SAND	46 – 54.2	ML
		LIGHT YELLOWISH BROWN PUMICEOUS SILTY MEDIUM TO COARSE SAND	54.2 – 54.6	
		GREYISH WHITE PUMICEOUS CLAYEY SILT WITH SOME MEDIUM TO COARSE SAND.	54.6 – 56.4	
Waikato Coal Measures		LIGHT YELLOW BROWN SILTY CLAY	56.4 – 57.3	
		CARBONACEOUS MUDSTONE	57.3 – 58.9	
			58.9	END OF BOREHOLE

Depth scale: 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59

DRILLER: G. Lewer

STARTED: 14.11.84

FINISHED: 15.12.84

DRILL: Gardner Denver 200T

WEATHERING: UW – Unweathered, SW – Slightly weathered, MW – Moderately weathered, HW – Highly weathered, CW – Completely weathered

HARDNESS: VH – Very hard, H – Hard, MH – Moderately hard, MS – Moderately soft, S – Soft, VS – Very soft

FRACTURE LOG (cms): Spacing of natural fractures 100 50 10 5 1; Fractures/m of core 1 2 10 20 100 1000

EXPLANATION

LOGGED: P. KELSEY
DATE: 26.8.85
TRACED:
CHECKED: P. KELSEY
VERTICAL SCALE: 1:50
SHEET 4 OF 5

PROJECT:
HOLE NO: 6655
LENGTH: 58.90
CORE BOXES:
DRG NO

LOG OF DRILL HOLE

PROJECT: HUNTLY SUBSIDENCE FEATURE: NZED HOSTEL LOCATION: RESERVE BEHIND KIMIHIA HOME HOLE NO. 6656

GRID REF. 626 14863mN 335 50181mE M.W.D. CO-ORD. DATUM: GEODETIC H.A.D. GROUND 11.59

ANGLE FROM HORIZONTAL DIRECTION PHOTO NO. H.A.D. COLLAR

DESCRIPTION OF CORE (FORMATION NAME; ROCK OR SOIL TYPE; DESCRIPTION OF CORE: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	WEATHERING (SW MW HW)	HARDNESS (H MH MS S)	POINT LOAD TEST (kPa)	CORE LOSS/LIFT %	DEPTH H.A.D. (Core size: casing)	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures)	ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc)	DATE/DEPTH	R.Q.D. %	WATER LEVEL	DRILL WATER LOSS %	WATER PRESSURE TESTS Permeability - LUGEONS
FILL: ORGANIC TOPSOIL													
FILL: DARK OLIVE BROWN CLAYEY FINE GRAVEL					1			fragments of indurated mudstone and coal in degraded clayey matrix GC					
FILL: LIGHT OLIVE BROWN/CREAM MEDIUM GRAVELLY COARSE SAND					2			massive; pumice rich with fireclay fragments. SP					
HINUERA FORMATION (?): LIGHT GREY GREEN ORGANIC RICH FINE SAND WITH SOME SILT					3			SP					
BLACK FIBROUS SILTY PEAT					4			transitional boundary					
LIGHT GREYISH BROWN ORGANIC RICH FINE SANDY SILTS					5			rootlets and stems common; rare rhyolite rock fragments 2mm Ø ML-Pt					
LIGHT GREEN BLUE SILT AND MINOR CLAY					6			ML					
BLACK PEAT								Pt					
LIGHT GREEN BLUE SANDY SILT WITH MINOR CLAY					7			rootlets, stems common ML					
					8			transitional boundary					
LIGHT GREY GREEN MEDIUM TO COARSE SAND WITH SOME FINE GRAVEL					9, 10			sand-quartz, feldspar rich with pumice and rhyolite fragments SW					
KARAPIRO FORMATION: SANDY SILT								transitional boundary					
LIGHT GREY BROWN SILTY MEDIUM TO COARSE SAND WITH SOME CLAY AND FINE GRAVEL.					11			quartz-feldspar rich with rhyolite (some banded) and pumice fragments SM					
					12			transitional boundary					
LIGHT GREY BROWN/GREEN COARSE SAND WITH MINOR FINE GRAVELS AND SILT.					13, 14			rock fragment dominated - rhyolite and pumice. SP					

DRILLER: G. LEKIER
STARTED: 12.12.84
FINISHED: 12.12.84
DRILL: GARDNER DENVER 200 T

WEATHERING: UW - Unweathered; SW - Slightly weathered; MW - Moderately weathered; HW - Highly weathered; CW - Completely weathered

HARDNESS: VH - Very hard; H - Hard; MH - Moderately hard; MS - Moderately soft; S - Soft; VS - Very soft

FRACTURE LOG (cms): Spacing of natural fractures / Fractures/m of core

EXPLANATION: 0-15.00 Wash Drilled

LOGGED: P.KELSEY DATE: 26.8.85 TRACED: CHECKED: P.KELSEY VERTICAL SCALE: 1:50

PROJECT: HOLE NO: 6656 LENGTH: 16.60 CORE BOXES:

SHEET 1 OF 4 DRG NO

EQ 3/25 M

LOG OF DRILL HOLE

PROJECT	Huntly Subsidence
FEATURE	NZED Hostel
LOCATION	Reserve Behind Kimihia Home
HOLE NO.	6656
GRID REF.	
M.W.D. CO-ORD.	
DATUM	Geodetic
ANGLE FROM HORIZONTAL	
DIRECTION	
PHOTO NO.	
H.A.D. GROUND	
H.A.D. COLLAR	

Formation	DESCRIPTION OF CORE (Formation name; Rock or soil type; Description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	DEPTH H.A.D (m)	ROCK STRUCTURES (Defects) (OR SOIL DESCRIPTION)
KARAPIRO / HINUERA FORMATION	DARK BROWNISH BLACK CLAYEY PEAT WITH MINOR COARSE SAND	16	Pt
KARAPIRO / HINUERA FORMATION	LIGHT YELLOW BROWN MEDIUM TO COARSE SAND WITH SOME FINE GRAVELS AND SILT	17–18	rock fragment dominated - rhyolite and pumice rare carbonaceous fragments SP
KARAPIRO / HINUERA FORMATION	YELLOWISH WHITE PUMICEOUS FINE GRAVELLY COARSE SAND	19	pumice rich SP
WHANGAMARINO FORMATION	DARK GREY BROWN PEATY MEDIUM TO COARSE SAND WITH MINOR GRAVELS		rootlets, bark common gravels pumice and rhyolite. SW-Pt
WHANGAMARINO FORMATION	LIGHT BLUE GREEN CLAYEY SILTS WITH MEDIUM TO COARSE SAND AND FINE GRAVELS.	20–22	carbonaceous fragments common rock fragments rhyolite and pumice CL
WHANGAMARINO FORMATION	LIGHT BLUE GREEN FINE GRAVELLY MEDIUM TO COARSE SAND AND SOME SILT	23	transitional boundary SM-SW
WHANGAMARINO FORMATION	LIGHT BLUE GREEN CLAYEY SILT WITH SOME MEDIUM TO COARSE SAND AND FINE GRAVEL.	24	rock fragments rhyolite and pumice CL
WHANGAMARINO FORMATION	LIGHT BLUE GREEN COARSE SAND WITH SOME MEDIUM SAND AND FINE GRAVELS	25–26	transitional boundary; rock fragment dominant - rhyolite and pumice. SP
WHANGAMARINO FORMATION	DARK BROWN PEATY SILT WITH SOME COARSE SAND	27	rootlets, bark common. Pt
WHANGAMARINO FORMATION	DARK BROWN COARSE SAND WITH SOME SILT.	28	carbonaceous fragments common SP
WHANGAMARINO FORMATION	SANDY SILT	29	ML-SM

Other column headings: WEATHERING (SW, MW, HW); HARDNESS (H, MH, MS, S); POINT LOAD TEST (kPa); CORE LOSS/LIFT % (5, 10, 50); Core size, casing; GRAPHIC LOG; FRACTURE LOG (Spacing of natural fractures) (50, 10, 5, 1 cms); DATE/DEPTH; R.Q.D. %; WATER LEVEL; DRILL WATER LOSS % (0–100); WATER PRESSURE TESTS Permeability - LUGEONS (.01, 0.1, 1, 10, 100, 1000); Date.

DRILLER: G. LEWER
STARTED: 12.12.84
FINISHED: 12.12.84
DRILL: Gardner-Denver 200T

WEATHERING
UW - Unweathered
SW - Slightly weathered
MW - Moderately weathered
HW - Highly weathered
CW - Completely weathered

HARDNESS
VH - Very hard
H - Hard
MH - Moderately hard
MS - Moderately soft
S - Soft
VS - Very soft

FRACTURE LOG
(cms) 100 50 10 5 1 0.1 — Spacing of natural fractures
1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION
15.00-30.00 Wash Drilled

LOGGED: P. KELSEY
DATE: 26.8.85
TRACED:
CHECKED: P. KELSEY
VERTICAL SCALE: 1:50
PROJECT:
HOLE NO: 6656
LENGTH: 46.60
CORE BOXES:
SHEET 2 OF 4
DRG NO

BQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6656

PROJECT: Huntly Subsidence   FEATURE: NZED Hostel   LOCATION: Reserve Behind Kimihia Home

GRID REF. ....   M.W.D. CO-ORD. ....   DATUM: Geodetic

ANGLE FROM HORIZONTAL ....   DIRECTION ....   PHOTO NO. ....   H.A.D. GROUND ....   H.A.D. COLLAR ....

DESCRIPTION OF CORE (Formation name; Rock or soil type; Description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	Depth H.A.D. (m)	Rock Structures (Defects) / (or Soil Description)
YELLOWISH GREY COARSE SAND WITH SOME SILT	31	SP
DARK GREY BROWN SANDY PEAT WITH SOME SILT	32	fibrous peat with abundant wood fragments Pt; transitional boundary
DARK GREY BROWN PEATY SILT WITH SOME SAND	33	
SILTY SAND		
IGNIMBRITIC LIGHT GREY PUMICEOUS CLAYEY SILT WITH SOME MEDIUM TO COARSE SAND	34–39	
IGNIMBRITIC LIGHT BLUE GREEN CLAYEY SILT WITH MEDIUM TO COARSE SAND	40	
LIGHT BROWN CLAYEY SILT	41–42	
LIGHT YELLOW BROWN MUDSTONE	43–44	mudstone soft at top, whitish yellow; drilling becoming difficult; END OF BOREHOLE AT 46.60m

Formation: WHANGAMARINO FORMATION (LOWER IGNIMBRITIC SILT UNIT); WAIKATO COAL MEASURES

WATER LEVEL: WATER LEVEL AT SURFACE WHEN DRILLING

Column headings: WEATHERING (SW MW HW); HARDNESS (H MH MS S); POINT LOAD TEST (kPa); CORE LOSS/LIFT; DEPTH H.A.D.; Core size, casing; GRAPHIC LOG; FRACTURE LOG (Spacing of natural fractures, cms); DATE/DEPTH; R.Q.D.; WATER LEVEL; DRILL WATER LOSS (0–100); WATER PRESSURE TESTS Permeability – LUGEONS

DRILLER: G. Lener

STARTED: 12.12.84

FINISHED: 12.12.84

DRILL: Gardner-Denver 200T

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms): Spacing of natural fractures; Fractures/m of core

EXPLANATION: 30.00–46.60 Wash Drilled.

LOGGED: P. Kelsey   DATE: 26.8.85   TRACED: ....   CHECKED: P. Kelsey   VERTICAL SCALE: 1:50

PROJECT: ....   HOLE NO: 6656   LENGTH: 46.60   CORE BOXES: ....

SHEET 3 OF 4   DRG NO ....

IQ 3/25 M

LOG OF DRILL HOLE

PROJECT	Huntly Subsidence
FEATURE	N.Z.E.D. Hostel
LOCATION	Reserve West of Rosser Street
HOLE NO.	6657
GRID REF.	625 966.65 335 270.35
M.W.D. CO-ORD.	
DATUM	Geodetic
H.A.D. GROUND	9.79
ANGLE FROM HORIZONTAL	090°
DIRECTION	
PHOTO NO.	
H.A.D. COLLAR	

Formation name	DESCRIPTION OF CORE (Formation name; rock or soil type; description of core: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	Depth H.A.D. (m)	ROCK STRUCTURES (Defects) Joints, veins, seams, shatter, shear & crush zones, foliation, schistosity (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc)
	DARK GREYISH BROWN PEATY SILT WITH SOME CLAY	0 – 1	Pt
	DARK BROWN SILTY PEAT	1 – 2.5	Pt, fibrous
	FLUVIATILE DARK BROWN CARBONACEOUS CLAYEY SILT	2.5 – 5	
	LIGHT OLIVE BROWN PUMICEOUS FINE SAND	5 – 6.8	saturated; loose; massive, dilatant SP
	PEAT	6.8 – 7.2	Pt - fibrous; branches 0.4m long
HINUERA FORMATION	FLUVIATILE LIGHT BROWNISH GREEN FINE SAND	7.2 – 8.2	rootlets; interbedded medium sand; saturated; loose; massive, SP
HINUERA FORMATION	LIGHT BLUE GREY PUMICEOUS SILTY MEDIUM TO COARSE SAND	8.2 – 8.8	wet; compact; massive SM
HINUERA FORMATION	FLUVIATILE LIGHT BLUE GREY CLAYEY SILT	8.8 – 9.8	wet; soft; massive
HINUERA FORMATION	FLUVIATILE LIGHT GREY GREEN PUMICEOUS MEDIUM TO COARSE SAND	9.8 – 11.2	saturated; loose; massive SM
HINUERA FORMATION	FLUVIATILE INTERBEDDED FINE SAND, SILTY FINE SAND AND CLAYEY SILT	11.2 – 12.2	sub-horizontal bedding at base; clayey silt carbonaceous at top (palaeosol)
HINUERA FORMATION	FLUVIATILE LIGHT YELLOW BROWN AND DARK BROWN PUMICEOUS MEDIUM TO COARSE SAND	12.2 – 14.8	
HINUERA FORMATION	CLAYEY SILT	14.8 –	

WEATHERING
- UW – Unweathered
- SW – Slightly weathered
- MW – Moderately weathered
- HW – Highly weathered
- CW – Completely weathered

HARDNESS
- VH – Very hard
- H – Hard
- MH – Moderately hard
- MS – Moderately soft
- S – Soft
- VS – Very soft

FRACTURE LOG (cms) Spacing of natural fractures / Fractures/m of core

DRILLER:	T. Brown
STARTED:	25.1.85
FINISHED:	29.1.85
DRILL:	Failing 1250
LOGGED:	P. Kelsey
DATE:	25-29.1.85
TRACED:	
CHECKED:	P. Kelsey
VERTICAL SCALE:	1:50
SHEET	1 OF 3
PROJECT:	
HOLE NO:	6657
LENGTH:	21.98
CORE BOXES:	
DRG NO.	

EXPLANATION

0-5.60 Wash Drilled
5.60-15.00 Cored
Zones of core loss interpreted from geophysical logs.

MQ 3/25 M

LOG OF DRILL HOLE

HOLE NO. 6657

PROJECT Huntly Subsidence FEATURE N.Z.E.D. Hostel LOCATION Reserve West of Rosser Street

GRID REF 625 966.65 335 270.35 M.W.D. CO-ORD. DATUM Geodetic H.A.D. GROUND 9.79

ANGLE FROM HORIZONTAL 090° DIRECTION PHOTO NO. H.A.D. COLLAR

DESCRIPTION OF CORE — FORMATION NAME. ROCK OR SOIL TYPE: DESCRIPTION OF CORE: (grain size, texture, mineral content, hardness, strength, cement & matrix colour).

SW MW HW WEATHERING | VH H MH MS S HARDNESS | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % (5 10 50) | DEPTH HAD | Core size, casing | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) 50 10 cms 5 | ROCK STRUCTURES (Defects) JOINTS VEINS SEAMS. SHATTER, SHEAR & CRUSH ZONES. FOLIATION. SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc) | DATE/DEPTH | R.Q.D. % | WATER LEVEL Date | DRILL WATER LOSS % 0-100 | WATER PRESSURE TESTS Permeability - LUGEONS .01 .1 1 10 100 1000

HINUERA FORMATION

Depth (m)	Description of core	Rock structures / soil description
to ~16.3	FLUVIATILE CLAYEY SILT	
~16.3 – 20.2	FLUVIATILE PUMICEOUS MEDIUM TO COARSE SANDY FINE GRAVEL	
20.2 – 21.98	FLUVIATILE LIGHT GREY GREEN AND DARK GREEN INTERBEDDED FINE SAND AND SILT	top of unit finely layered medium and fine sand SW bedding 10° SM
21.98		END OF BOREHOLE

Depth scale: 16, 17, 18, 19, 20, 21, 22, 23, 24, 25

DRILLER: T Brown

STARTED: 25.1.85

FINISHED: 29.1.85

DRILL: Failing 1250

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms): 100 50 10 5 1 0 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION

15.00 – 21.98 Cored

Zones of core loss interpreted from geophysical logs.

LOGGED: I Kelsey DATE: 25-27.1.85 TRACED: CHECKED: P Kelsey VERTICAL SCALE: 1:50

PROJECT: HOLE NO: 6657 LENGTH: 21.98 CORE BOXES:

SHEET 2 OF 3 DRG NO

EQ 3/25 M

LOG OF DRILL HOLE

N.Z.E.Q

PROJECT: Hostel Subsidence
FEATURE
GRID REF.: N56 691 763
M.W.D. CO-ORD.
ANGLE FROM HORIZONTAL: 90°
DIRECTION
HOLE NO.: 6599
LOCATION: Burke Pl. Huntly
DATUM
PHOTO NO.
H.A.D. GROUND
H.A.D. COLLAR

Formation	Description of core	Rock structures (Defects) / Soil description
Karapiro – Hamilton Ashes	ORGANIC TOP SOIL	
	YELLOWISH BROWN CLAYEY GRAVEL (FILL)	
	LIGHT YELLOWISH BROWN SILTY CLAY (IGNIMBRITIC)	moist; soft; finely bedded (sub hori. – mm scale); CH.
	CREAMY YELLOW PUMICEOUS SILTY SAND (MEDIUM) WITH SOME GRAVEL	moist; loose; bedding cm scale formed by alignment of manganese (?) nodules; SW. Fe-oxide staining top 0.7m of unit.
	OLIVE WHITE PUMICEOUS CLAYEY SILT	moist; loose; bedded (cm scale); ML.
	CORE LOSS	
	OLIVE WHITE PUMICEOUS SILTY SAND (COARSE) WITH SOME GRAVEL	moist; loose; massive; SW.
	INTERBEDDED PUMICEOUS CLAYEY SILT AND SILTY SAND (COARSE)	moist; loose; bedding variable 0.1–0.2m (sub-horizontal). Clayey Silt – ML Silty Sand – SW. Manganese nodules common
	BANDED LIGHT OLIVE BROWN AND OLIVE WHITE PUMICEOUS SILTY SAND (COARSE) WITH SOME FINE GRAVEL BECOMING FINER AT BASE	moist, loose; bedded (cm scale) at base; SW. Unit clay rich at basal 0.2m.
	INTERBEDDED YELLOWISH BROWN SANDY GRAVEL (MEDIUM) WITH SOME SILT AND BROWNISH YELLOW PUMICEOUS SILTY SAND (MEDIUM)	moist; loose; massive; SW. ↑ gradational boundary. moist; loose; massive; GM. Subrounded greywacke – 5mm ø. Subangular ignimbrite – 20mm ø
Karapiro Formation	CORE LOSS	
	YELLOWISH BROWN PUMICEOUS SILTY SAND (MEDIUM) WITH SOME FINE GRAVEL.	moist; loose; bedded (1cm – 5cm); SM. Manganese (?) nodules common.
	CORE LOSS	
	BROWNISH YELLOW PUMICEOUS SAND (COARSE)	↑ gradational boundary. moist; loose; massive; SP. Interbed of pumiceous silty clay at 30°
	CORE LOSS	
	IGNIMBRITIC REDDISH BROWN PUMICEOUS SAND (COARSE) WITH SOME SILT.	Alternating dark reddish brown and light yellowish brown horizons 1–6cm thick at top of unit. moist; loose; bedding cm scale; SM. Fe-oxide staining 0.3m above GM. 6cm band cream clayey silt capping gravels
	YELLOWISH BROWN SANDY (COARSE) FINE GRAVEL WITH SOME SILT.	dry; loose; massive; GM.
	CORE LOSS	
	YELLOWISH BROWN SAND (COARSE) WITH SOME SILT. INTERBEDS (15%) OF SAND (MEDIUM-FINE) WITH SOME SILT. (IGNIMBRITIC)	moist; loose; bedding cm scale; SW.
	CORE LOSS	
	YELLOWISH WHITE SILTY SAND (MEDIUM). (IGNIMBRITIC)	moist; compact; massive; SP
	CORE LOSS	

Core size – HQ3 – Clay core shoe. HW casing to 4.50m.

Depth (m): 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Date/depth: 13-1-83; 14-1-83

Samples: 1, 2, 3, 4

Water level: 13-1 4.00 pm; 14-1 6.30 am; 14-1 4.00 pm (NVO); 17-1 5.45 pm (NVO); 17-1 5.30 pm (NVO); 19-1 6.45 am (NVO); 15-1 6.30 am; 18-1 8.00 am (NVO)

DRILLER: T. Bolton	WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered	HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft	FRACTURE LOG (cms): Spacing of natural fractures / Fractures/m of core
STARTED: 13.1.83	EXPLANATION		LOGGED: P. Kelsey; DATE: 23.12.83; TRACED:; CHECKED:; VERTICAL SCALE: 1:50
FINISHED: 21.1.83			PROJECT: Huntly Subs.; HOLE NO: 6599; LENGTH: 52 m; CORE BOXES: Nos 1-3
DRILL: Longyear 38			SHEET 1 OF 4; DRG NO

EQ 3/25 M

LOG OF DRILL HOLE

N.Z.E.D.

PROJECT: Hostel Subsidence
FEATURE:
LOCATION: Bure Pl. Huntly
HOLE NO.: 6599
GRID REF.: N56 691 763
M.W.D. CO-ORD.:
DATUM:
ANGLE FROM HORIZONTAL: 90°
DIRECTION:
H.A.D. GROUND:
PHOTO NO.:
H.A.D. COLLAR:

DESCRIPTION OF CORE (FORMATION NAME: ROCK OR SOIL TYPE: DESCRIPTION OF CORE: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	DEPTH H.A.D. (m)	ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES: FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.)
YELLOWISH WHITE SILTY SAND (MEDIUM) (IGNIMBRITIC)	to approx. 15.8	
CORE LOSS	approx. 15.8–16	
LIGHT YELLOWISH BROWN MOTTLED SILTY SAND (MEDIUM) WITH SOME FINE GRAVEL. (IGNIMBRITIC)	approx. 16.4–26	clayey silt; silty fine sand. Fine sand 'inclusions' orientated 30-70°. — moist; compact; massive; SW. Rare pumice pebbles approx. 1cm dia. Rare manganese (?) nodules approx 0.5cm dia. Bedding contact 35°
LIGHT YELLOWISH OLIVE PUMICEOUS SILTY SAND (FINE) WITH SOME CLAY. (FLUVIATILE)	26–29.3	— wet; compact; massive; SM. Top 0.2m of unit bedded 2-4cm scale - light and dark horizons.
LIGHT OLIVE BROWN PUMICEOUS CLAYEY SILT WITH SOME FINE SAND. (FLUVIATILE)	29.3–	— moist; compact; massive

Formation (written vertically beside the descriptions): KARAPIRO FORMATION

Date/Depth: 14-1-83; 15-1-83

Samples: 5, 6, 7

Water level (date notes): 17-1 3.00pm (nvo); 17-1 4.00am (nvo); 20-1 1.30pm (nvo); 21-1 8.45am; 20-1 10.30am (nvo)

WEATHERING: UW - Unweathered; SW - Slightly weathered; MW - Moderately weathered; HW - Highly weathered; CW - Completely weathered

HARDNESS: VH - Very hard; H - Hard; MH - Moderately hard; MS - Moderately soft; S - Soft; VS - Very soft

FRACTURE LOG (cms): Spacing of natural fractures; Fractures/m of core

DRILLER: T. Bolton
STARTED: 13.1.83
FINISHED: 21.1.83
DRILL: Longyear 38

EXPLANATION

LOGGED: P. Kelsey
DATE: 23.12.83
TRACED:
CHECKED:
VERTICAL SCALE: 1:50
PROJECT: Huntly Subs
HOLE NO: 6599
LENGTH: 52m
CORE BOXES: Nos 3-5
SHEET 2 OF 3
DRG NO

EQ 3/25 M

LOG OF DRILL HOLE

N.Z.E.D.

PROJECT: HOSTEL SUBSIDENCE FEATURE

LOCATION: BURKE PL. HUNTLY

HOLE NO.: 6599

GRID REF.: N56 691 743

M.W.D. CO-ORD.:

DATUM:

H.A.D. GROUND:

ANGLE FROM HORIZONTAL: 90°

DIRECTION:

PHOTO NO.:

H.A.D. COLLAR:

DESCRIPTION OF CORE (FORMATION NAME; ROCK OR SOIL TYPE; DESCRIPTION OF CORE: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	DEPTH H.A.D.	ROCK STRUCTURES (Defects) JOINTS. VEINS: SEAMS: SHATTER, SHEAR & CRUSH ZONES: FOLIATION: SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.)	DATE/DEPTH	SAMPLE
LIGHT YELLOWISH GREY PUMICEOUS CLAYEY SILT WITH SOME FINE SAND.		moist; stiff; massive; ML		8
YELLOWISH BROWN PUMICEOUS SILTY SAND (FINE) WITH SOME CLAY.	31	gradational boundary; moist; compact; massive; SM-SC. Fe-oxide staining top 7cm of unit.		
LIGHT YELLOWISH GREY PUMICEOUS CLAYEY SILT WITH SOME FINE SAND. (FLUVIATILE)		grad. bound.; moist; stiff; massive;		
LIGHT YELLOWISH GREY PUMICEOUS SILTY SAND (FINE) WITH SOME CLAY.	32	grad. bound.; moist; compact; bedding highly variable 1cm-20cm. SM.	17-1-83	
	33			9
	34	Bedding 0-10°		
	35	Rare manganese (?) nodules; Sand 'inclusions'		
	36	Bedding 0-10°. Interbeds of sandy silt on cm scale		
	37			
BROWNISH YELLOW SANDY GRAVELS WITH SOME SILT.		grad. bound.; moist; loose; massive; GM; Fe-oxide stained.		
CORE LOSS				
LIGHT YELLOWISH GREY SILTY SAND (FINE) WITH SOME CLAY	38	moist; compact; massive; SM.		
LIGHT YELLOWISH OLIVE SANDY (COARSE) GRAVELS (FINE) WITH SOME SILT.	39	moist; loose; massive; GP.		
CORE LOSS			18-1-83	
GREENISH WHITE CLAY		moist; very soft; finely bedded (mm scale); CH		
YELLOWISH BROWN SANDY GRAVELS (FINE)	40	graded bedding (reverse)		
CORE LOSS				
LIGHT YELLOWISH GREY GRAVELLY (FINE) SANDS (COARSE) WITH SOME SILT.	41	moist; loose; massive; SP. Interbed of GP, bedding 10°.		
LIGHT YELLOWISH OLIVE PUMICEOUS SILTY SANDS (MEDIUM) WITH SOME CLAY.	42	grad. bound.; moist; compact; bedded (cm scale) with silt rich and silt poor horizons. SM		10
	43			
DARK YELLOWISH BROWN CLAYEY SILT WITH SOME SAND (MEDIUM)		grad. bound.; moist; firm; massive; Fe-oxide staining including 3cm siderite "hard-pan"; ML		
PEAT		Pt		
OLIVE WHITE SILTY CLAY WITH SOME SAND (FINE) (FLUVIATILE)	44	moist; soft; massive; ML?		11

Formation names (side column): KARAPIRO FORMATION; WHANGAMARINO

Column headings: SW MW HW WEATHERING; VH H MH MS S HARDNESS; POINT LOAD TEST (kPa); CORE LOSS/LIFT %; Core size, casing; GRAPHIC LOG; FRACTURE LOG (Spacing of natural fractures) cms; WATER LEVEL Date; DRILL WATER LOSS % 0-100; WATER PRESSURE TESTS Permeability - LUGEONS .01 .1 1 10 100 1000

DRILLER: T. BOLTON

STARTED: 13/1/83

FINISHED: 21/1/83

DRILL: LONGYEAR 38

WEATHERING: UW - Unweathered; SW - Slightly weathered; MW - Moderately weathered; HW - Highly weathered; CW - Completely weathered

HARDNESS: VH - Very hard; H - Hard; MH - Moderately hard; MS - Moderately soft; S - Soft; VS - Very soft

FRACTURE LOG (cms) Spacing of natural fractures; Fractures/m of core

EXPLANATION

LOGGED: P. Kelsey

DATE: 23/12/83

TRACED:

CHECKED:

VERTICAL SCALE: 1:50

PROJECT: HUNTLY SUBS.

HOLE NO: 6599

LENGTH: 52m

CORE BOXES: No's 5-8

SHEET 3 OF 4

DRG NO

IQ 3/25 M

N.Z.E.D.

LOG OF DRILL HOLE

HOLE NO. 6599

PROJECT Hostel Subsidence FEATURE
LOCATION Burke Pl. Huntly
GRID REF. N56 691 743 M.W.D. CO-ORD.
DATUM
ANGLE FROM HORIZONTAL
DIRECTION
H.A.D. GROUND
PHOTO NO.
H.A.D. COLLAR

DESCRIPTION OF CORE (FORMATION NAME; ROCK OR SOIL TYPE; DESCRIPTION OF CORE: grain size, texture, mineral content, hardness, strength, cement & matrix colour)	DEPTH H.A.D. (m)	ROCK STRUCTURES (Defects) (OR SOIL DESCRIPTION)	DATE/DEPTH	SAMPLES
Whangamarino Formation: DARK YELLOWISH OLIVE GRAVELLY (FINE) SAND (MEDIUM) WITH SOME SILT.	46, 47, 48	moist; compact; massive; SW. Subrounded gravels up to 10mm ø. Rounded gravels up to 20mm ø at base of unit. Base of unit bedded (cm scale) with gravel rich and gravel poor horizons.		12
LIGHT YELLOWISH GREEN PUMICEOUS SAND (MEDIUM) WITH SOME SILT.	48, 49, 50	moist; loose; massive; SP. Top 0.3m of unit bedded (mm scale)	19-1-83	13
LIGHT BROWNISH OLIVE SANDY (COURSE) GRAVELS (FINE) WITH SOME SILT.	51, 52	gradational boundary. moist; loose; massive; GM. Sandy interbeds 20mm wide.	20-1	14

END OF BORE.

Column headings: WEATHERING (SW MW HW); HARDNESS (H MH MS S); POINT LOAD TEST (kPa); CORE LOSS/LIFT %; DEPTH H.A.D. (Core size, casing, m); GRAPHIC LOG; FRACTURE LOG (Spacing of natural fractures) cms 50 10 5 2; WATER LEVEL (Date); DRILL WATER LOSS % 0-100; WATER PRESSURE TESTS Permeability – LUGEONS (.01 .1 1 10 100 1000)

ROCK STRUCTURES: JOINTS, VEINS, SEAMS; SHATTER, SHEAR & CRUSH ZONES; FOLIATION; SCHISTOSITY (attitude, thickness, spacing, smoothness) (consistency, compactness, water content, group symbol etc.)

DRILLER: T. Bolton
STARTED: 13.1.83
FINISHED: 21.1.83
DRILL: Longyear 38

WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered

HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft

FRACTURE LOG (cms): Spacing of natural fractures; Fractures/m of core

EXPLANATION

LOGGED: P Kelsey
DATE: 23.12.83
TRACED:
CHECKED:
VERTICAL SCALE: 1:50
PROJECT: Huntly Subs
HOLE NO: 6599
LENGTH: 52m
CORE BOXES: Nos 8-9
SHEET 4 OF 4
DRG NO.

SUMMARY LOG

HOLE NO. 6651

PROJECT *Huntly Subsidence* FEATURE *NZED Hostel* LOCATION *Hostel Grounds*

GRID REF. *625 987.10 335 490.70* M.W.D. CO-ORD. DATUM *Geodetic*

ANGLE FROM HORIZONTAL *090* DIRECTION PHOTO NO. H.A.D. GROUND *21.73*

H.A.D. COLLAR

Formation	DESCRIPTION OF CORE (FORMATION NAME: ROCK OR SOIL TYPE: DESCRIPTION OF CORE: (grain size, texture, mineral content, hardness, strength, cement & matrix colour))	Unit
KAUROA-HAMILTON ASHES	CLAYEY SILT	
KAUROA-HAMILTON ASHES	IGNIMBRITIC PUMICEOUS SANDY SILT WITH SOME CLAY	UPPER IGNIMBRITIC SILT
KARAPIRO FORMATION	IGNIMBRITIC PUMICEOUS SILTY FINE TO MEDIUM SAND WITH SOME GRANULES	
KARAPIRO FORMATION	FLUVIATILE FINELY LAYERED PUMICEOUS FINE SAND	
KARAPIRO FORMATION	PUMICEOUS MEDIUM TO COARSE SAND, FINELY LAYERED PUMICEOUS FINE SAND AND SILTY SAND WITH MINOR GREYWACKE - RHYOLITE SANDY FINE TO MEDIUM GRAVELS	
WHANGAMARINO FORMATION	PALEOSOL: CARBONACEOUS CLAYEY SILT SANDY FINE-MEDIUM GRAVELS AND SILTY SAND	
WHANGAMARINO FORMATION	FLUVIATILE CLAYEY SILT WITH SOME FINE TO MEDIUM SAND	
WHANGAMARINO FORMATION	IGNIMBRITIC PUMICEOUS SILTY FINE TO MEDIUM SAND WITH SOME GRANULES	
WHANGAMARINO FORMATION	FLUVIATILE PUMICEOUS FINE TO MEDIUM SAND AND PUMICEOUS CLAYEY SILT	
WHANGAMARINO FORMATION	IGNIMBRITIC PUMICEOUS FINE TO MEDIUM, SANDY SILT WITH SOME CLAY	LOWER IGNIMBRITIC SILT
WHANGAMARINO FORMATION	IGNIMBRITIC / FLUVIATILE PUMICEOUS SILTY FINE TO MEDIUM SAND AND FINE TO MEDIUM GRAVELS	
WHANGAMARINO FORMATION	FINE TO MEDIUM SANDY SILT WITH SOME CLAY.	
WHANGAMARINO FORMATION	FINE TO MEDIUM GREYWACKE GRAVELS	
WHANGAMARINO FORMATION	SILTY/SANDY MEDIUM GRAVELS, SILTY FINE SAND AND SANDY SILT	
WAIKATO COAL MEASURES	CARBONACEOUS MUDSTONE	

Column headings: SW MW HW WEATHERING | H MH MS S HARDNESS | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % (5 20 50) | DEPTH H.A.D (Core size, casing, m) | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms) | ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.) | DATE/DEPTH | R.Q.D. % | WATER LEVEL (Date) | DRILL WATER LOSS % (0-100) | WATER PRESSURE TESTS Permeability - LUGEONS (0.1 1 10 100 1000)

Depth scale: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70

End of Borehole

DRILLER: *T. Brown*	WEATHERING: UW – Unweathered; SW – Slightly weathered; MW – Moderately weathered; HW – Highly weathered; CW – Completely weathered	HARDNESS: VH – Very hard; H – Hard; MH – Moderately hard; MS – Moderately soft; S – Soft; VS – Very soft	FRACTURE LOG (cms) 100 50 10 5 1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core
STARTED: *8.1.85*	EXPLANATION		
FINISHED: *14.1.85*			
DRILL: *Failing 1250*			

LOGGED: *P. Kelsey*	PROJECT:
DATE: *8.1.85 – 14.1.85*	HOLE NO. *6651*
TRACED:	LENGTH: *67.25*
CHECKED: *P. Kelsey*	CORE BOXES:
VERTICAL SCALE: *1:250*	
SHEET *6* OF *6*	DRG NO.

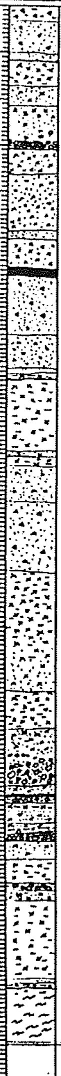
EQ 3/25 M

SUMMARY LOG

HOLE NO. 6652

PROJECT: Huntly Subsidence FEATURE: NZED Hostel LOCATION: Rosser Street
GRID REF.: (25 330 26 335 339 26 M.W.D. CO-ORD.: DATUM: Geodetic H.A.D. GROUND: 12.04
ANGLE FROM HORIZONTAL: 090° DIRECTION: PHOTO NO.: H.A.D. COLLAR:

DESCRIPTION OF CORE — FORMATION NAME	ROCK OR SOIL TYPE / DESCRIPTION OF CORE (grain size, texture, mineral content, hardness, strength, cement & matrix colour)	WEATHERING (SW MW HW)	HARDNESS (H MH MS S)	POINT LOAD TEST (kPa)	CORE LOSS/LIFT % (5 10 50)	DEPTH H.A.D. (Core size, casing)	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) (50 10 5 cms)	ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES; FOLIATION; SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.)	DATE/DEPTH	R.Q.D. %	WATER LEVEL (Date)	DRILL WATER LOSS % (0–100)	WATER PRESSURE TESTS Permeability – LUGEONS (·01 ·1 1 10 100 1000)
	FILL: RECOMPACTED FIRECLAY AND SAND													
KARAPIRO / HINUERA FORMATIONS(?)	INTERBEDDED PUMICEOUS SANDY SILT, MEDIUM TO COARSE SAND, SILTY MEDIUM TO COARSE SAND WITH MINOR CLAYEY SILT, SANDY FINE GRAVEL AND PEAT.					5, 10, 15								
WHANGAMARINO FORMATION	CLAYEY SILT WITH MINOR SANDY SILT					20								
	PUMICEOUS SILTY MEDIUM TO COARSE SAND					25								
	PUMICEOUS MEDIUM TO COARSE SAND WITH MINOR FINE GRAVEL.													
	CLAYEY SILT					30								
	SILTY MEDIUM TO COARSE SAND					35								
	CLAYEY SILT													
	INTERBEDDED SANDY FINE TO MEDIUM GRAVELS, SANDY SILT, SILTY SAND AND MINOR PEAT.					40								
	SILTY MEDIUM TO COARSE SAND					45								
	PUMICEOUS CLAYEY SILT													
	FINE GRAVELS AND SILTY MEDIUM TO COARSE SAND													
	CLAYEY SILT					50								
WAIKATO COAL MEASURES	CARBONACEOUS MUDSTONE					55			END OF BOREHOLE					
						60								



DRILLER: T. Brown
STARTED: 21.1.85
FINISHED: 23.1.85
DRILL: Failing 1250

WEATHERING
UW – Unweathered
SW – Slightly weathered
MW – Moderately weathered
HW – Highly weathered
CW – Completely weathered

HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very soft

FRACTURE LOG (cms)
100 50 10 5 1 0·1 — Spacing of natural fractures
1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION

LOGGED: P. Kelsey PROJECT:
DATE: HOLE NO.: 6652
TRACED: LENGTH: 55.75
CHECKED: P. Kelsey CORE BOXES:
VERTICAL SCALE: 1:250
SHEET 5 OF 5 DRG NO.

EQ 3/25 M

SUMMARY LOG

PROJECT HUNTLY SUBSIDENCE FEATURE N.Z.E.D. HOSTEL LOCATION RESERVE EAST OF ROSSER ST HOLE NO. 6653

GRID REF. 625 936.00 335 421.30 M.W.D. CO-ORD. DATUM GEODETIC

ANGLE FROM HORIZONTAL 090° DIRECTION H.A.D. GROUND 16.99

PHOTO NO. H.A.D. COLLAR

DESCRIPTION OF CORE — FORMATION NAME. ROCK OR SOIL TYPE. DESCRIPTION OF CORE (grain size, texture, mineral content, hardness, strength, cement & matrix colour).	WEATHERING SW MW HW	HARDNESS H MH MS S	POINT LOAD TEST (kPa)	CORE LOSS/LIFT % 5 10 50	DEPTH H.A.D. Core size, casing m	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) 50 10 5 cms	ROCK STRUCTURES (Defects) JOINTS. VEINS. SEAMS: SHATTER., SHEAR & CRUSH ZONES: FOLIATION. SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.)	DATE/DEPTH	R.Q.D. %	WATER LEVEL Date	DRILL WATER LOSS % 0-100	WATER PRESSURE TESTS Permeability - LUGEONS .01 .1 1 10 100 1000
KAUROA-HAMILTON A: IGNIMBRITIC PUMICEOUS SANDY SILT													
KARAPIRO FORMATION: PEAT					5								
FLUVIATILE SILTY MEDIUM TO COARSE SAND													
MEDIUM GRAVELS					10								
IGNIMBRITIC PUMICEOUS SILTY FINE SAND					15								
PUMICEOUS FINE SAND, MEDIUM TO COARSE SAND AND CLAYEY SILT					20								
WHANGAMARINO FORMATION: PALEOSOL: CARBONACEOUS CLAYEY SILT					25								
FLUVIATILE CLAYEY SILT AND SILTY SAND					30								
IGNIMBRITIC SILTY SAND					35								
IGNIMBRITIC MEDIUM TO COARSE SAND													
FLUVIATILE CLAYEY SILT					40								
SANDY FINE GRAVELS, CLAYEY SILT AND MEDIUM SAND													
IGNIMBRITIC SANDY SILT (LOW 16 SILT)					45								
IGNIMBRITIC MEDIUM SAND (LOW 16 SILT)					50								
FLUVIATILE CLAYEY SILT, SANDY SILT AND SANDY GRAVELS.					55								
SANDY/SILTY GRAVEL					60								
WAIKATO COAL MEASURES: CARBONACEOUS MUDSTONE					65								

DRILLER: T BROWN
STARTED: 11.1.85
FINISHED: 18.1.85
DRILL: FAILING 1250

WEATHERING
UW - Unweathered
SW - Slightly weathered
MW - Moderately weathered
HW - Highly weathered
CW - Completely weathered

HARDNESS
VH - Very hard
H - Hard
MH - Moderately hard
MS - Moderately soft
S - Soft
VS - Very soft

FRACTURE LOG (cms) 100 50 10 5 1 — Spacing of natural fractures; 1 2 10 20 100 1000 — Fractures/m of core

EXPLANATION

LOGGED: P.KELSEY
DATE: 16-18.1.85
TRACED:
CHECKED: P.KELSEY
VERTICAL SCALE: 1:250
SHEET 6 OF 6 DRG NO

PROJECT:
HOLE NO: 6653
LENGTH: 61.60
CORE BOXES:

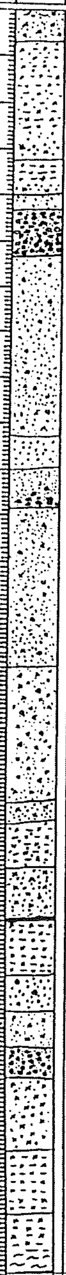
SUMMARY LOG

HOLE NO. 6654

PROJECT: Huntly Subsidence. FEATURE: N.Z.E.D. Hostel
LOCATION: Burke Place
GRID REF: 625 981·85 N. 335 638·83 E M.W.D. CO-ORD.
DATUM: Geodetic
ANGLE FROM HORIZONTAL: 090° DIRECTION:
PHOTO NO.:
H.A.D. GROUND: 41·59
H.A.D. COLLAR:

DESCRIPTION OF CORE (Formation name; Rock or soil type; Description of core (grain size, texture, mineral content, hardness, strength, cement & matrix colour))		WEATHERING (SW, MW, HW)	HARDNESS (H, MH, MS, S)	POINT LOAD TEST (kPa)	CORE LOSS/LIFT % (5, 10, 50)	DEPTH H.A.D. (Core size, casing) m	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) (50, 10, 5 cms)	ROCK STRUCTURES (Defects): JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.)	DATE/DEPTH	R.Q.D. %	WATER LEVEL (Date)	DRILL WATER LOSS % (0–100)	WATER PRESSURE TESTS Permeability – LUGEONS (·01, ·1, 1, 10, 100, 1000)
Kauroa–Hamilton Ashes	Ignimbritic pumiceous clayey silt, silty sand and coarse sand. (Upper ignimbritic silt)													
Karapiro Formation	Sandy gravels and medium to coarse sand													
	Medium to coarse sand													
	Pumiceous coarse sand													
	Medium to coarse sand and sandy fine gravel													
	Fine to medium sand													
	Silty fine sand													
	Pumiceous silty fine sand, clayey silt, and sandy silt.													
Whangamarino Formation	Paleosol: organic clayey silt													
	Fluviatile clayey silt													
	Coarse sand, silty fine sand and fine gravels													
	Ignimbritic pumiceous sandy silt (Lower ignimbritic unit)													
	Silty clay													
Waikato Coal Measures	Siltstone													

Depth scale: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70



DRILLER: G. Lewer
STARTED: 17·12·84
FINISHED: 20·12·84
DRILL: Gardner Denver 200T

WEATHERING
UW – Unweathered
SW – Slightly weathered
MW – Moderately weathered
HW – Highly weathered
CW – Completely weathered

HARDNESS
VH – Very hard
H – Hard
MH – Moderately hard
MS – Moderately soft
S – Soft
VS – Very soft

FRACTURE LOG
(cms) 100, 50, 10, 5, 1, 0·1 — Spacing of natural fractures
1, 2, 10, 20, 100, 1000 — Fractures/m of core

EXPLANATION

LOGGED: P. Kelsey
DATE: 27·8·85
TRACED:
CHECKED: P. Kelsey
VERTICAL SCALE: 1:250
SHEET 6 OF 6
PROJECT:
HOLE NO: 6654
LENGTH:
CORE BOXES:
DRG NO

EQ 3/25 M

SUMMARY LOG

HOLE NO. 6655

PROJECT: HUNTLY SUBSIDENCE — FEATURE: NZED HOSTEL — LOCATION: HOSTEL GROUNDS
GRID REF: 626 063 63mN 335 57888mE — M.W.D. CO-ORD: — DATUM: GEODETIC
ANGLE FROM HORIZONTAL: — DIRECTION: — H.A.D. GROUND: 27.78
PHOTO NO.: — H.A.D. COLLAR:

Formation	Unit	Description of core	Depth (m)
KAUAEA-HAMILTON ASH	UPPER IGNIMBRITIC SILT UNIT	IGNIMBRITIC PUMICEOUS SILTY SAND AND SANDY SILT	5
KARAPIRO FORMATION		IGNIMBRITIC PUMICEOUS FINE TO MEDIUM SAND	10, 15, 20, 25
KARAPIRO FORMATION		FLUVIATILE SANDY FINE GRAVEL, CLAYEY SILT AND COARSE SAND	30
NHANGAMARINO FORMATION		PALEOSOL: SILTY PEAT	
NHANGAMARINO FORMATION		FLUVIATILE SILTY CLAY	35
NHANGAMARINO FORMATION		SILTY COARSE/MEDIUM SAND AND SANDY GRAVEL	40
NHANGAMARINO FORMATION	LOWER IGNIMBRITIC SILT UNIT	IGNIMBRITIC CLAYEY SILT	45, 50
NHANGAMARINO FORMATION		PUMICEOUS SILTY SAND, AND CLAYEY SILT	55
WAIKATO COAL MEASURES		CARBONACEOUS MUDSTONE.	60

Column headings: DESCRIPTION OF CORE (FORMATION NAME; ROCK OR SOIL TYPE; DESCRIPTION OF CORE (grain size, texture, mineral content, hardness, strength, cement & matrix colour)) | WEATHERING (SW, MW, HW) | HARDNESS (H, MH, MS, S) | POINT LOAD TEST (kPa) | CORE LOSS/LIFT % | DEPTH H.A.D (Core size, casing) | GRAPHIC LOG | FRACTURE LOG (Spacing of natural fractures) | ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES, FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc) | DATE/DEPTH | R.Q.D. % | WATER LEVEL (Date) | DRILL WATER LOSS % (0-100) | WATER PRESSURE TESTS Permeability - LUGEONS (.01, .1, 1, 10, 100, 1000)

DRILLER: GLEWER
STARTED: 14.12.84
FINISHED: 15.12.84
DRILL: GARDNER-DENVER 200T

WEATHERING	HARDNESS	FRACTURE LOG (cms)
UW - Unweathered	VH - Very hard	Spacing of natural fractures: 100, 50, 10, 5, 1, 0.1
SW - Slightly weathered	H - Hard	Fractures/m of core: 1, 2, 10, 20, 100, 1000
MW - Moderately weathered	MH - Moderately hard	
HW - Highly weathered	MS - Moderately soft	
CW - Completely weathered	S - Soft	
	VS - Very soft	

EXPLANATION

LOGGED: P.KELSEY — PROJECT:
DATE: 26.8.85 — HOLE NO: 6655
TRACED: — LENGTH: 58.90
CHECKED: P.KELSEY — CORE BOXES:
VERTICAL SCALE: 1:250
SHEET 5 OF 5 — DRG NO

IQ 3/25 M

SUMMARY LOG

HOLE NO. 6656

PROJECT: *HUNTLY SUBSIDENCE* — FEATURE: *N.Z.E.D. HOSTEL*

GRID REF.: *626 148·63 mN 335506·81 mE* — M.W.D. CO-ORD.: ....

LOCATION: *RESERVE BEHIND KIMIHIA HOME*

DATUM: *GEODETIC*

ANGLE FROM HORIZONTAL: .... DIRECTION: ....

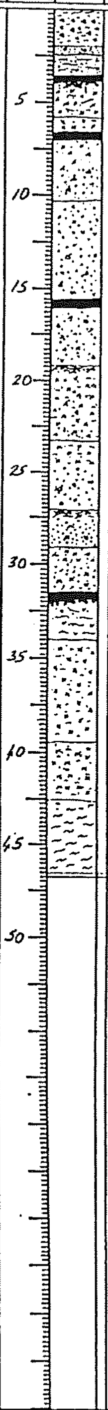
PHOTO NO.: ....

H.A.D. GROUND: *11.59*

H.A.D. COLLAR: ....

DESCRIPTION OF CORE — FORMATION NAME: / ROCK OR SOIL TYPE: / DESCRIPTION OF CORE (grain size, texture, mineral content hardness, strength, cement & matrix colour).	
	FILL RECOMPACTED FIRECLAY AND SAND
KARAPIRO/HINUERA FORMATION	ORGANIC RICH FINE SAND
KARAPIRO/HINUERA FORMATION	INTERBEDDED SANDY SILT, SILT AND PEAT
KARAPIRO/HINUERA FORMATION	SANDY SILT AND MEDIUM TO COARSE SAND
KARAPIRO/HINUERA FORMATION	SILTY MEDIUM TO COARSE SAND AND COARSE SAND
KARAPIRO/HINUERA FORMATION	CLAYEY PEAT
KARAPIRO/HINUERA FORMATION	MEDIUM TO COARSE SAND WITH SOME FINE GRAVELS AND SILT
WHANGAMARINO FORMATION	PEATY MEDIUM TO COARSE SAND, CLAYEY SILTS AND FINE GRAVELLY MEDIUM TO COARSE SAND
WHANGAMARINO FORMATION	CLAYEY SILT WITH SOME SAND AND COARSE SAND WITH SOM FINE GRAVEL
WHANGAMARINO FORMATION	PEATY SILT AND COARSE SAND
WHANGAMARINO FORMATION	SANDY SILT AND COARSE SAND
WHANGAMARINO FORMATION	SANDY PEAT AND PEATY SILT
WHANGAMARINO FORMATION	PUMICEOUS CLAYEY SILT WITH SOME MEDIUM TO COARSE SAND (LW. IG. UNIT)
WHANGAMARINO FORMATION	CLAYEY SILT WITH MEDIUM TO COARSE SAND
WAIKATO COAL MEASURES	MUDSTONE

Column headings: SW / MW / HW WEATHERING — H / MH / MS / S HARDNESS — POINT LOAD TEST (kPa) — CORE LOSS/LIFT % (5, 10, 50) — DEPTH H.A.D (Core size, casing) m — GRAPHIC LOG — FRACTURE LOG (Spacing of natural fractures) (50, 10, 5, 1 cms) — ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS: SHATTER, SHEAR & CRUSH ZONES: FOLIATION; SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc) — DATE/DEPTH — R.Q.D. % — WATER LEVEL (Date) — DRILL WATER LOSS % (0–100) — WATER PRESSURE TESTS Permeability – LUGEONS (.01, .1, 1, 10, 100, 1000)



END OF BOREHOLE

DRILLER: *G. LEWER*

STARTED: *12.12.84*

FINISHED: *12.12.84*

DRILL: *GARDNER-DENVER 200 T*

WEATHERING	HARDNESS
UW – Unweathered	VH – Very hard
SW – Slightly weathered	H – Hard
MW – Moderately weathered	MH – Moderately hard
HW – Highly weathered	MS – Moderately soft
CW – Completely weathered	S – Soft
	VS – Very soft

FRACTURE LOG (cms): 100, 50, 10, 5, 1, 0.1 — Spacing of natural fractures; 1, 2, 10, 20, 100, 1000 — Fractures/m of core

EXPLANATION

LOGGED: *P. KELSEY* — PROJECT: ....

DATE: *26.8.85* — HOLE NO.: *6656*

TRACED: .... — LENGTH: *46.60*

CHECKED: *P. KELSEY* — CORE BOXES: ....

VERTICAL SCALE: *1:250*

SHEET *4* OF *4* — DRG NO ....

EQ 3/25 M

SUMMARY LOG

HOLE NO. 6657

PROJECT: Huntly Subsidence FEATURE: N.Z.E.D. Hostel

LOCATION: Reserve West of Rosser Street

GRID REF: 625 966:65 335 270:35 M.W.D. CO-ORD.

DATUM: Geodetic

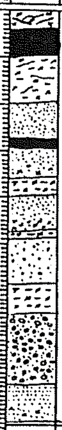
ANGLE FROM HORIZONTAL: 090° DIRECTION

H.A.D. GROUND: 9.79

PHOTO NO.

H.A.D. COLLAR

DESCRIPTION OF CORE FORMATION NAME: ROCK OR SOIL TYPE: DESCRIPTION OF CORE (grain size, texture, mineral content, hardness, strength, cement & matrix colour).	WEATHERING SW MW HW	HARDNESS H MH MS S	POINT LOAD TEST (kPa)	CORE LOSS/ LIFT % 5 10 50	DEPTH H.A.D. Core size. casing m	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) 50 10 5 cms	ROCK STRUCTURES (Defects) JOINTS. VEINS. SEAMS: SHATTER, SHEAR & CRUSH ZONES: FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc)	DATE/DEPTH	R.Q.D. %	WATER LEVEL Date	DRILL WATER LOSS % 0-100	WATER PRESSURE TESTS Permeability - LUGEONS .01 .1 1 10 100 1000
PEATY SILT													
SILTY PEAT													
CLAYEY SILT (FLUVIATILE)													
PUMICEOUS FINE SAND AND PEAT (FLUVIATILE)					5								
FLUVIATILE MEDIUM TO COARSE SAND, CLAYEY SILT AND FINE SAND					10								
FLUVIATILE SANDY FINE GRAVEL					15								
FLUVIATILE FINE SAND AND SILT					20								
					25								



DRILLER:	WEATHERING	HARDNESS	FRACTURE LOG		
STARTED:	UW - Unweathered SW - Slightly weathered MW - Moderately weathered HW - Highly weathered CW - Completely weathered	VH - Very hard H - Hard MH - Moderately hard MS - Moderately soft S - Soft VS - Very soft	(cms) 100 50 10 5 1 0.1 Spacing of natural fractures 1 2 10 20 100 1000 Fractures/m of core	LOGGED: DATE:	PROJECT: HOLE NO:
FINISHED:	EXPLANATION			TRACED: CHECKED:	LENGTH: CORE BOXES:
DRILL:				VERTICAL SCALE:	
				SHEET ... OF ...	DRG NO

EQ 3/25 M

SUMMARY LOG

HOLE NO. 6599

PROJECT: HUNTLY SUBSIDENCE
FEATURE: N.Z.E.D. HOSTEL
LOCATION: HOSTEL AMENITIES BLOCK
GRID REF.: N56 691 763
M.W.D. CO-ORD.:
DATUM:
H.A.D. GROUND:
ANGLE FROM HORIZONTAL: 090°
DIRECTION:
PHOTO NO.:
H.A.D. COLLAR:

DESCRIPTION OF CORE — FORMATION NAME. ROCK OR SOIL TYPE: DESCRIPTION OF CORE (grain size, texture, mineral content, hardness, strength, cement & matrix colour).		SW MW HW WEATHERING	H MH MS S HARDNESS	POINT LOAD TEST (kPa)	CORE LOSS/LIFT % 5 10 50	DEPTH H.A.D Core size, casing m	GRAPHIC LOG	FRACTURE LOG (Spacing of natural fractures) 50 10 5 cms	ROCK STRUCTURES (Defects) JOINTS, VEINS, SEAMS, SHATTER, SHEAR & CRUSH ZONES; FOLIATION, SCHISTOSITY (attitude, thickness, spacing, smoothness) (OR SOIL DESCRIPTION) (consistency, compactness, water content, group symbol etc.)	DATE/DEPTH	R.Q.D. %	WATER LEVEL Date	DRILL WATER LOSS % 0-100	WATER PRESSURE TESTS Permeability - LUGEONS .01 .1 1 10 100 1000
KAUROA-HAMILTON A	IGNIMBRITIC PUMICEOUS SILTY SAND AND CLAYEY SILT													
KARAPIRO FORMATION	PUMICEOUS SILTY SAND, COARSE SAND AND SANDY GRAVELS.					5								
	IGNIMBRITIC PUMICEOUS SILTY SAND					10, 15, 20								
	FLUVIATILE SILTY FINE SAND					25								
	SILTY SAND, CLAYEY SILT AND SANDY GRAVELS					30, 35								
	SANDY GRAVELS													
	GRAVELLY SAND AND SILTY SAND					40								
WHANGAMARINO FM	PALEOSOL SILTY CLAY													
	GRAVELLY SAND AND PUMICEOUS MEDIUM SAND					45								
	SANDY GRAVELS					50								
						55								

DRILLER:	WEATHERING: UW - Unweathered; SW - Slightly weathered; MW - Moderately weathered; HW - Highly weathered; CW - Completely weathered	HARDNESS: VH - Very hard; H - Hard; MH - Moderately hard; MS - Moderately soft; S - Soft; VS - Very soft	FRACTURE LOG (cms): 100 50 10 5 1 0 Spacing of natural fractures; 1 2 10 20 100 1000 Fractures/m of core	LOGGED: / PROJECT:
STARTED:				DATE: / HOLE NO:
FINISHED:	EXPLANATION			TRACED: / LENGTH:
DRILL:				CHECKED: / CORE BOXES:
				VERTICAL SCALE:
				SHEET ... OF ... / DRG NO

LQ 3/25 M

APPENDIX 3: Geophysical logs and penetrometer soundings

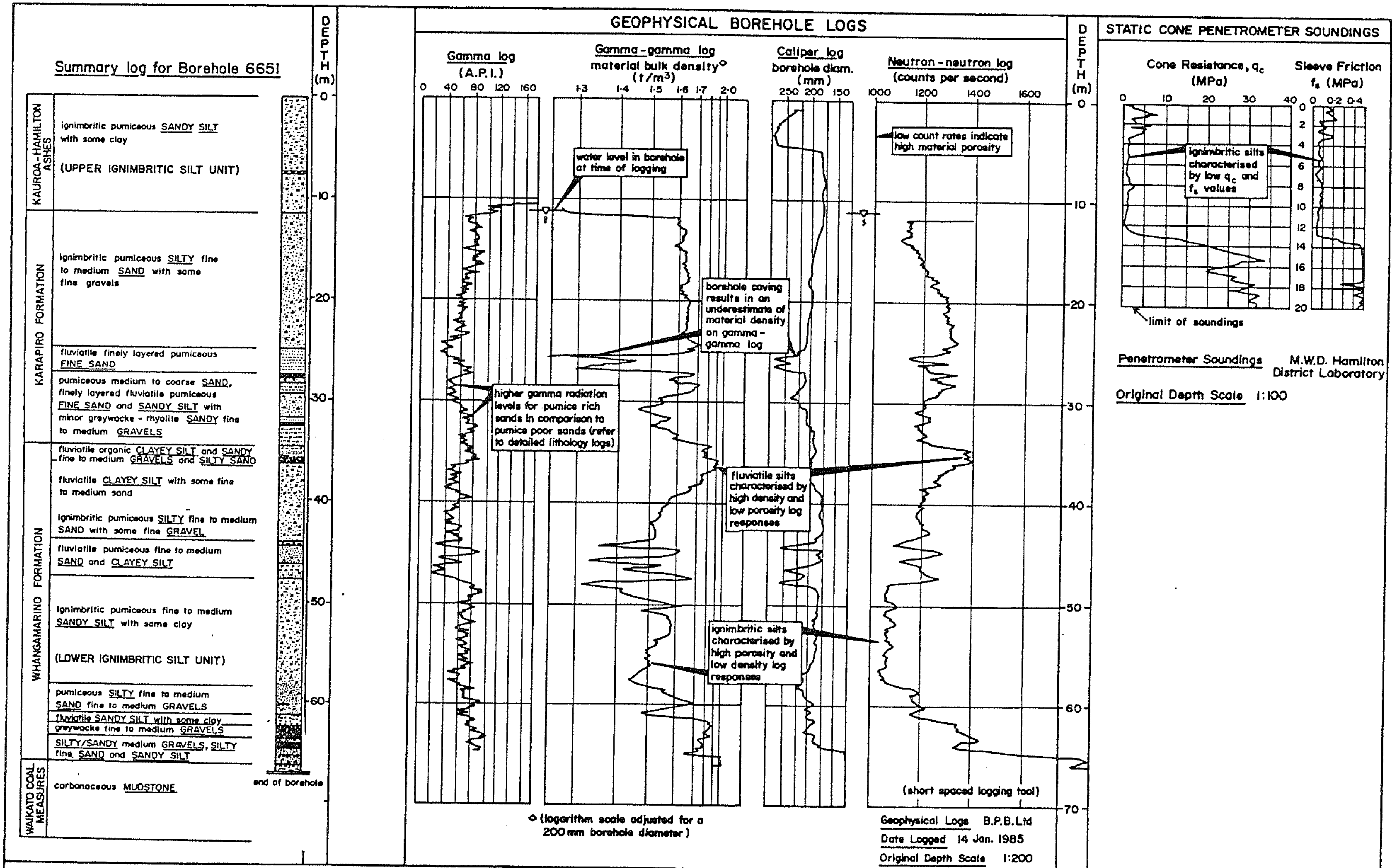


Figure A3.0 : Field Data Logs for Borehole 6651

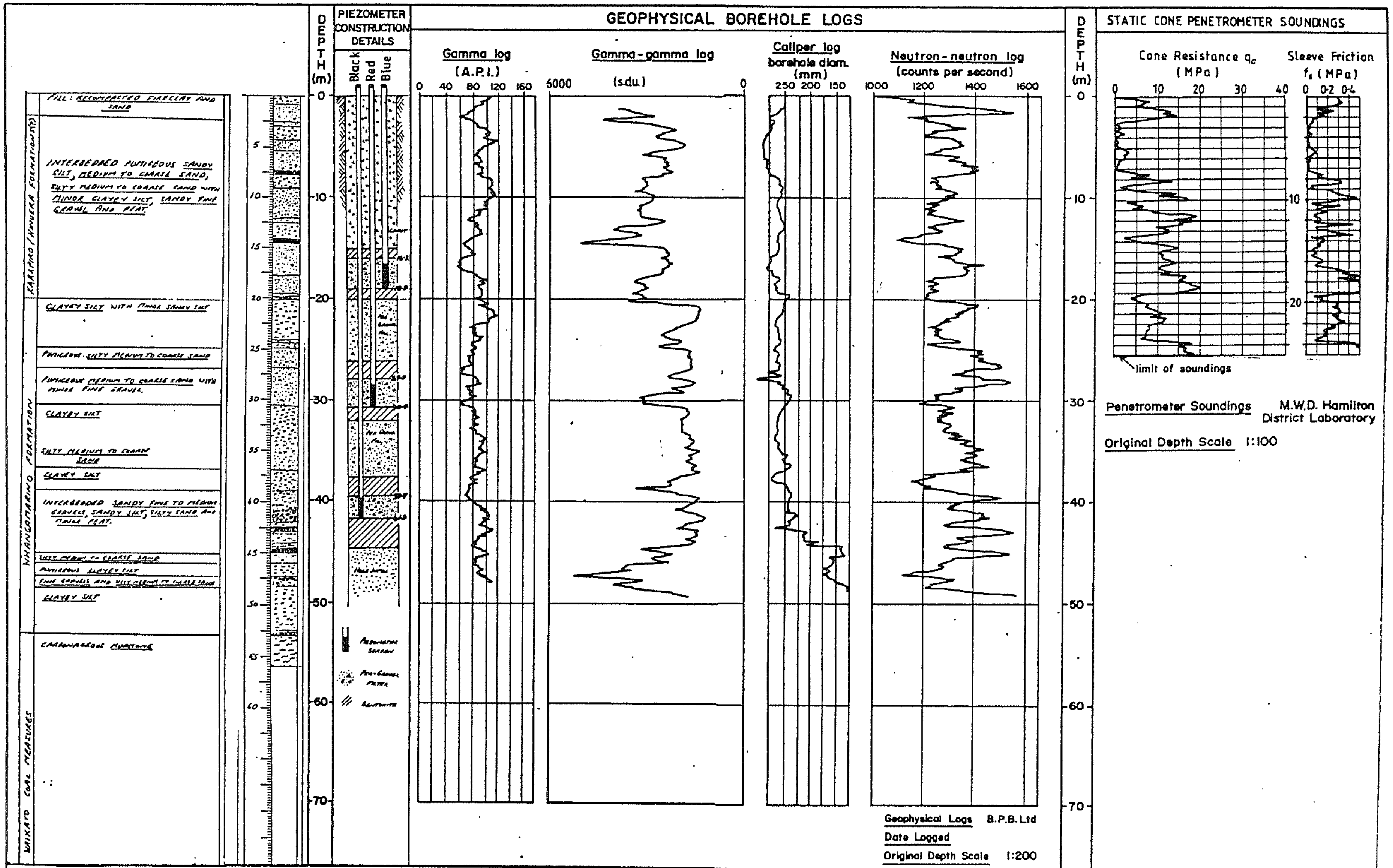


Figure A3·1: Field Data Logs for Borehole 6652

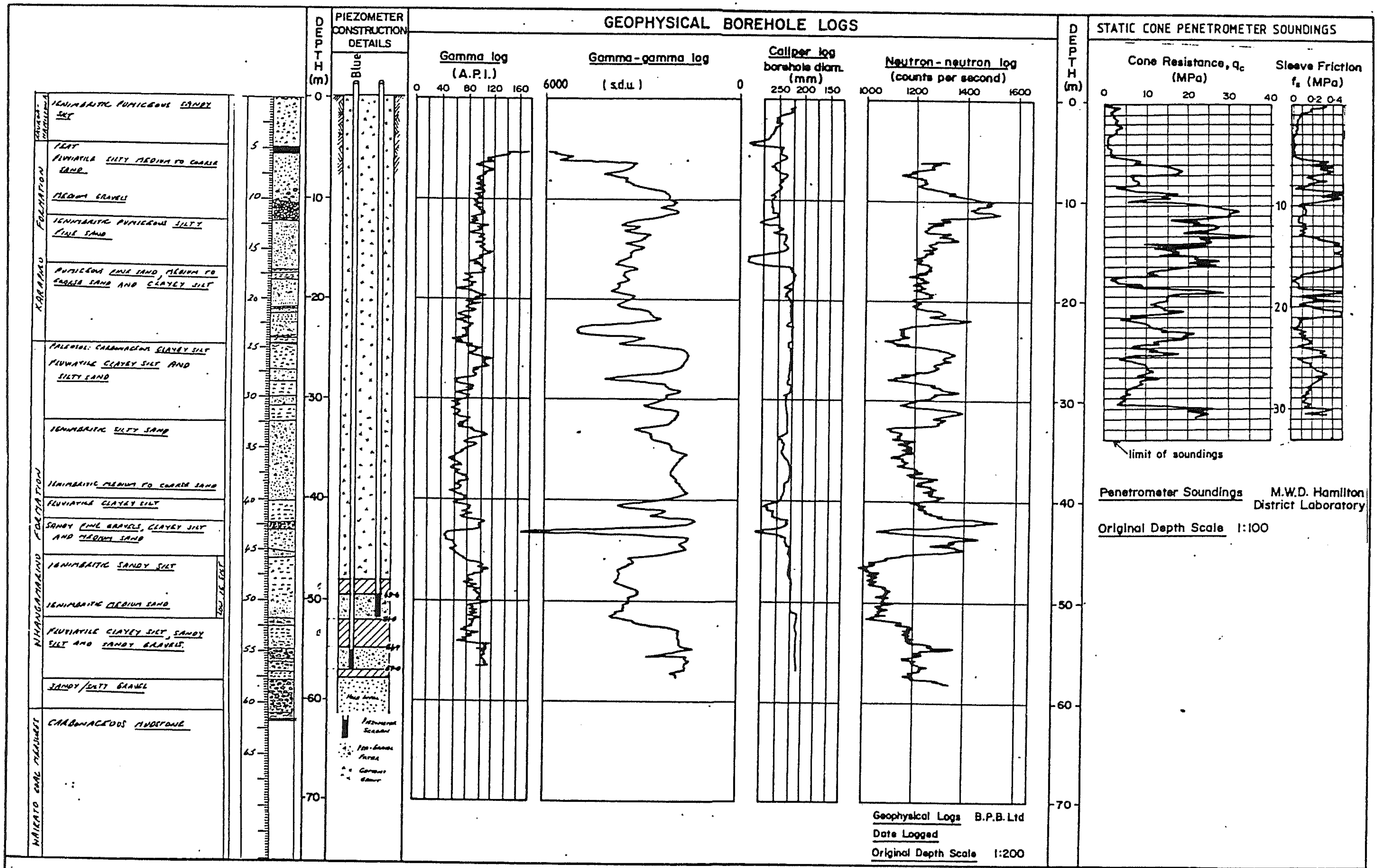


Figure A 3·2: Field Data Logs for Borehole 6653

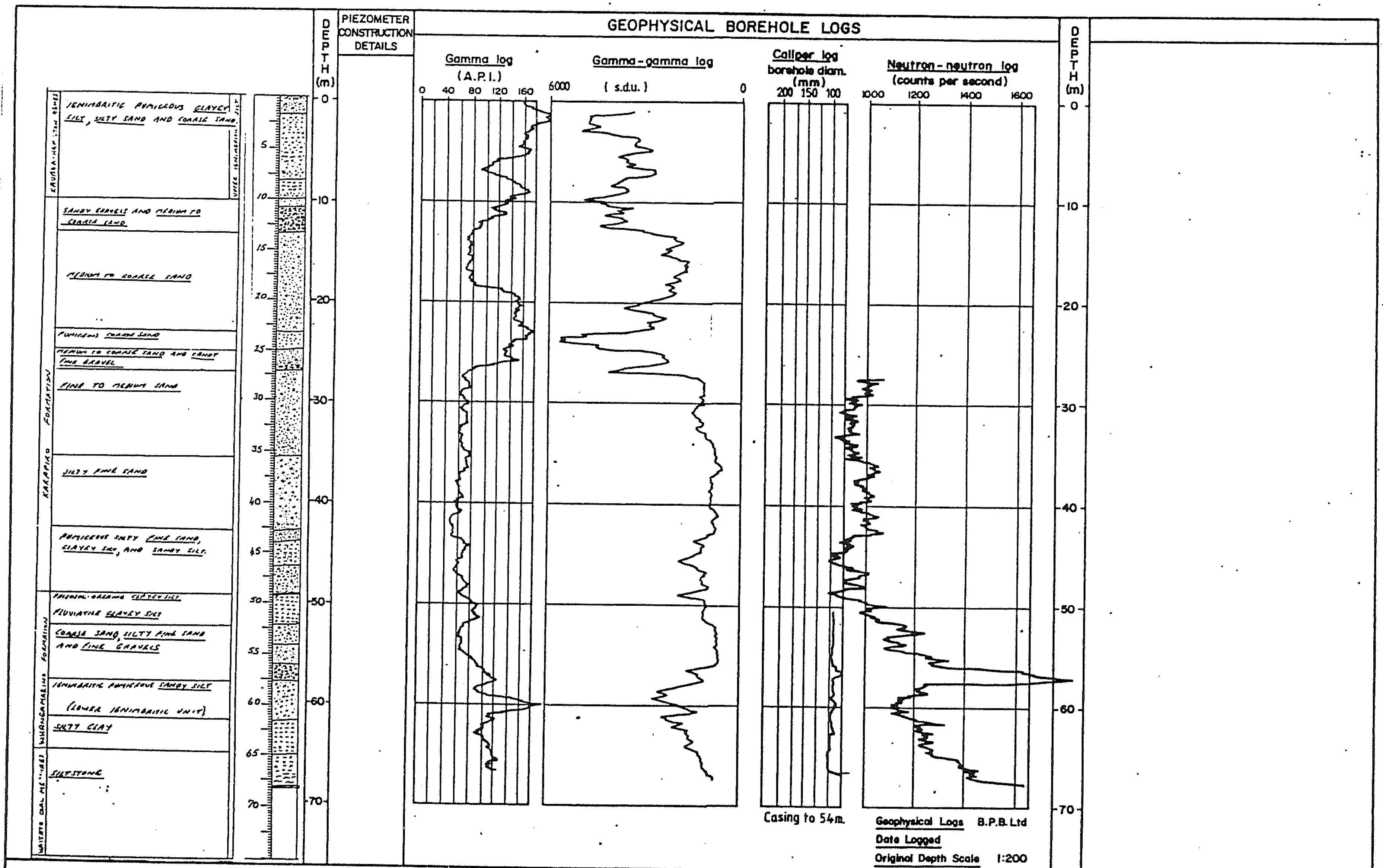


Figure A 3.3: Field Data Logs for Borehole 6654

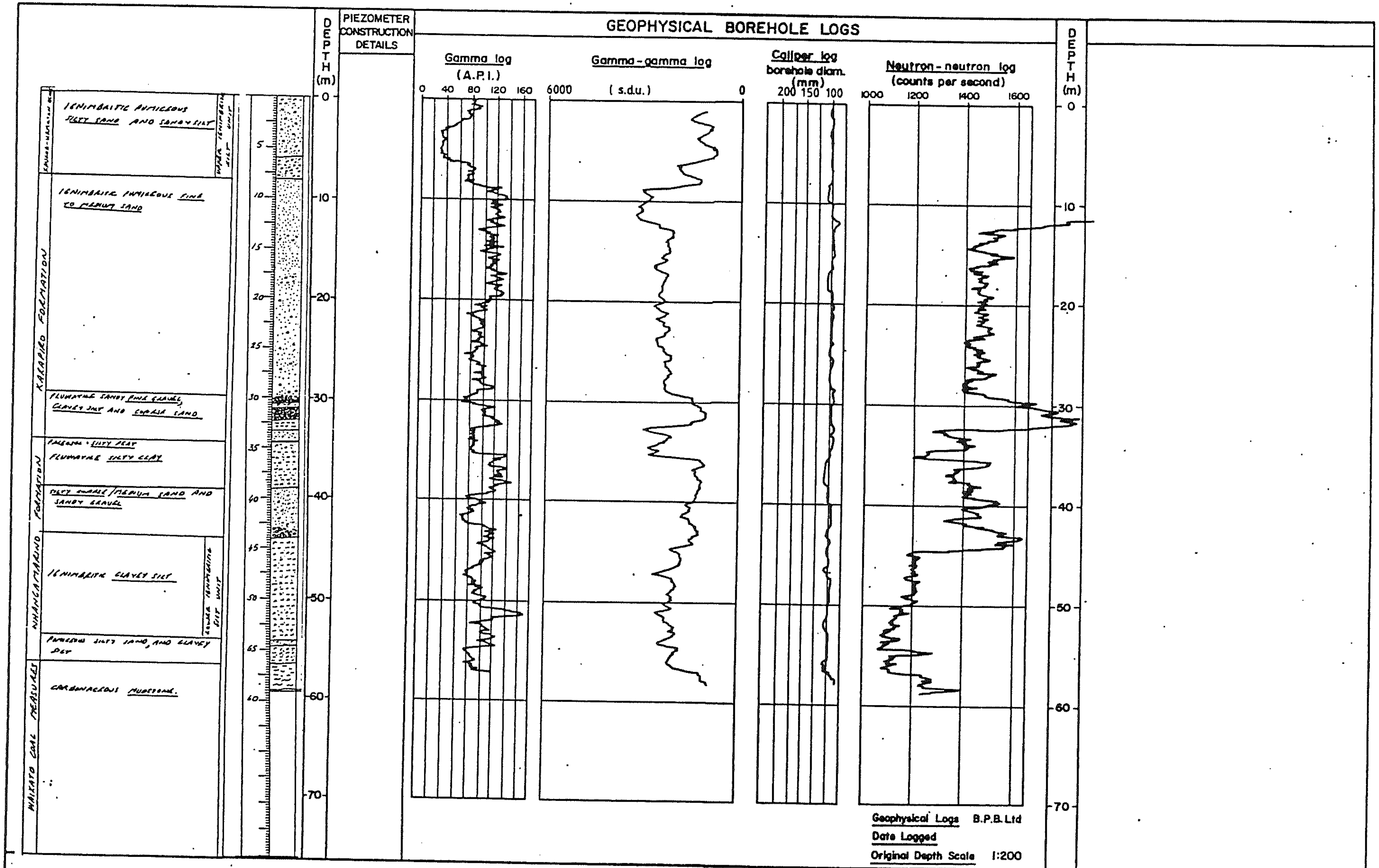


Figure A 3·4: Field Data Logs for Borehole 6655

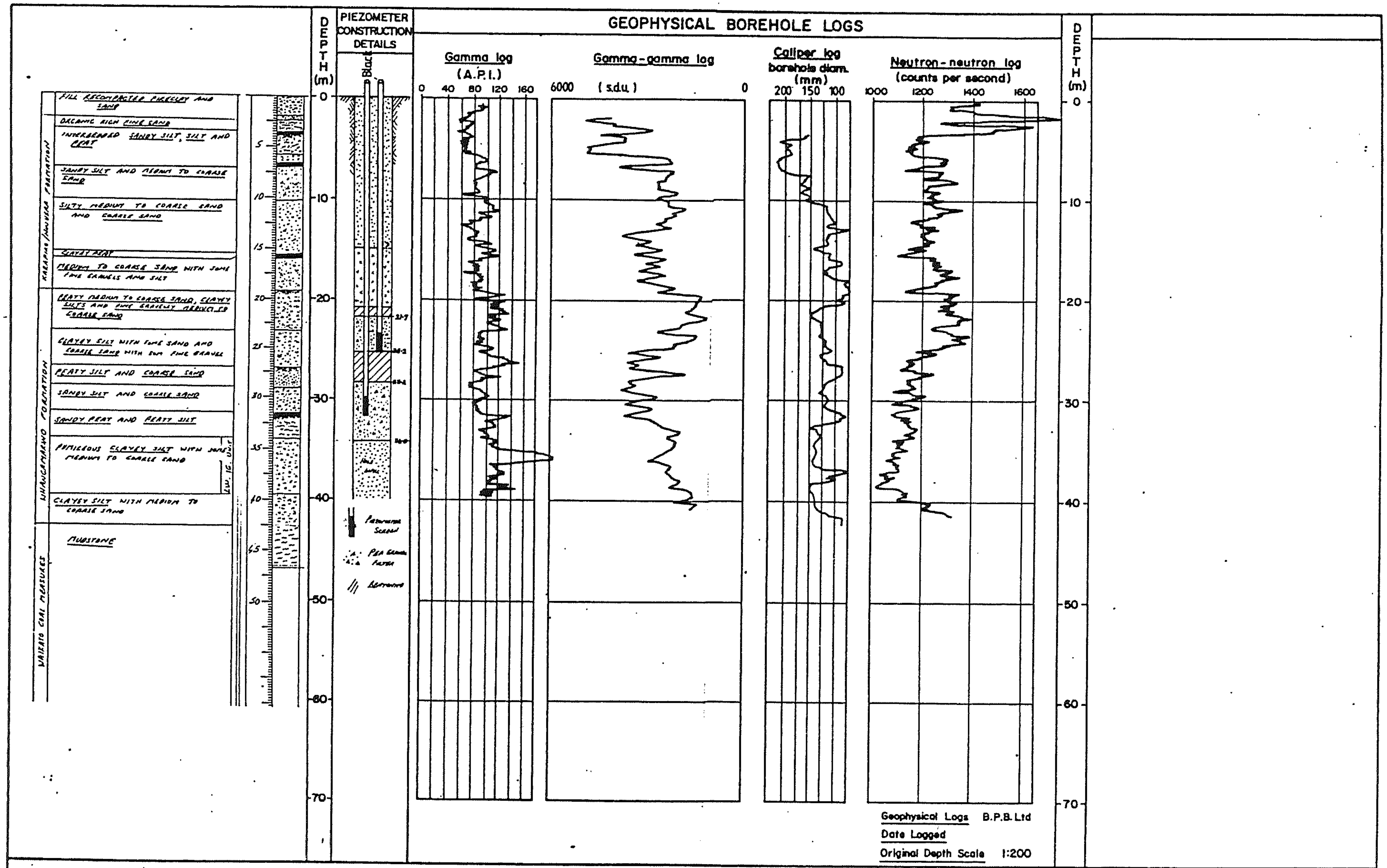


Figure A 3.5: Field Data Logs for Borehole 6656

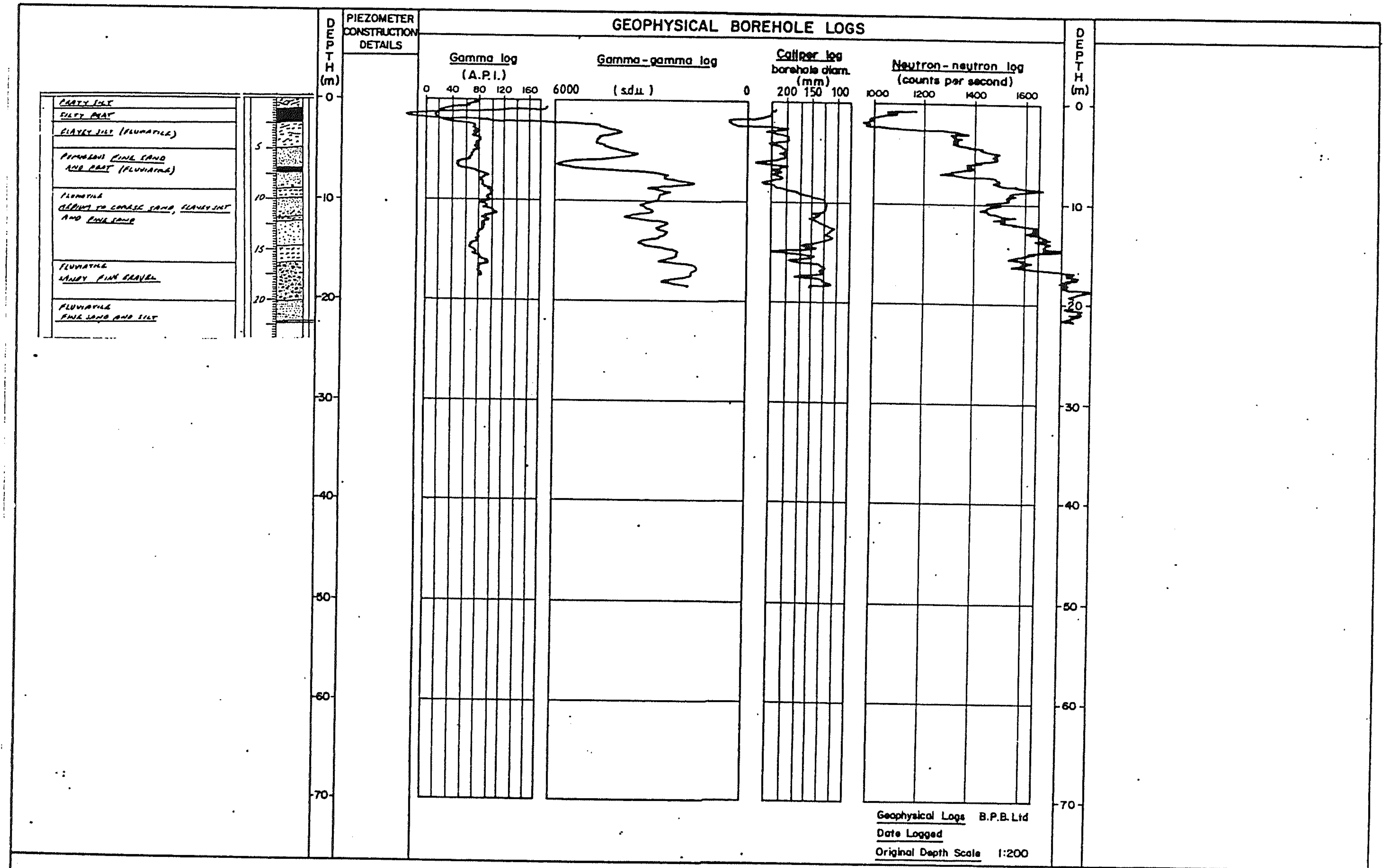


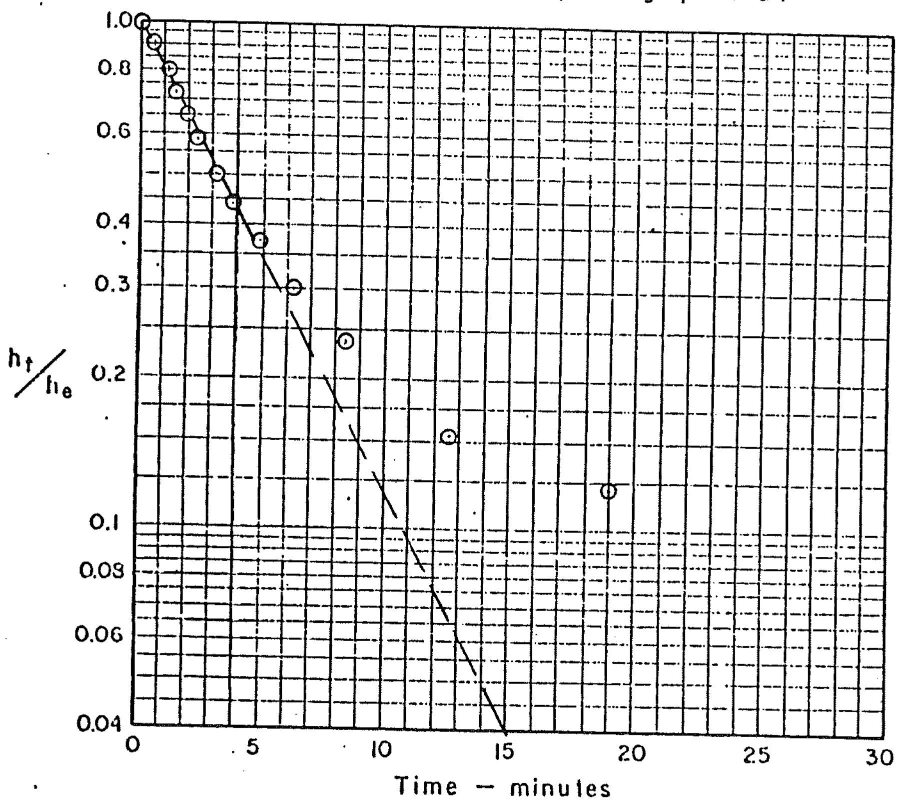
Figure A 3·6: Field Data Logs for Borehole 6657

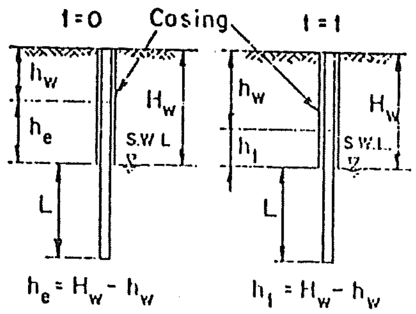
APPENDIX 4: Field permeability falling head test data

FALLING HEAD TEST	Test N°	Date 31/1/85	Project HUNTLY SUBSIDENCE
	Engineer P KELSEY		Borehole 6652-RED
Borehole co-ordinates		Collar elevation	
Depth to top of test section 27.90 m		Length of test section, L 2.8 m	
Depth of static water level, H_w 7.14 m		Radius of borehole, r m	
Excess head, h_e 7.14 m		Radius of standpipe or casing, r_c 0.02 m	

Time, T (min)	0.17	0.32	0.50	0.67	1.03	1.43	1.92	2.45	3.10	3.90	4.93	6.37	8.47	12.65	19
Depth to water, h_w (m)	0.25	0.50	0.75	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.29
Excess head, $h_t = H_w - h_w$ (m)	6.89	6.64	6.39	6.14	5.64	5.14	4.64	4.14	3.64	3.14	2.64	2.14	1.64	1.14	0.85
h_t / h_e	0.97	0.93	0.90	0.86	0.79	0.72	0.65	0.58	0.51	0.44	0.37	0.30	0.23	0.16	0.12

Head - time graph (slope of graph is S)





Calculations

Permeability $k = 0.133\, S \left(\frac{r_c^2}{L}\right)$ m/sec.

$S = \frac{\log_{10}\left(\frac{1.0}{0.04}\right)}{15} = 9.32 \times 10^{-2}$

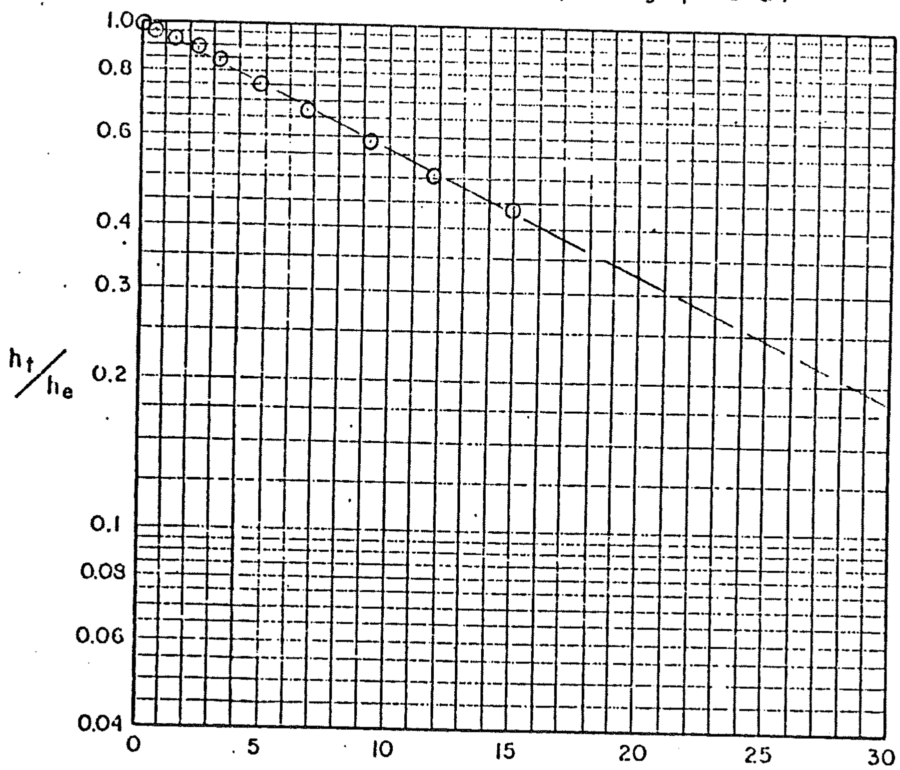
$k = 1.77 \times 10^{-6}$ m/s

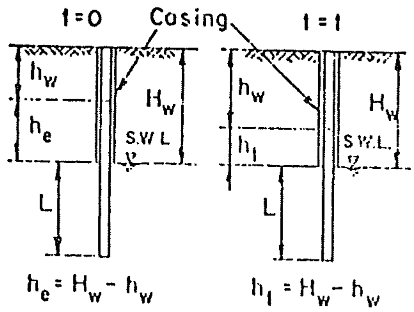
FALLING HEAD TEST	Test N°	Date 31.1.85	Project HUNTLY SUBSIDENCE
	Engineer P. KELSEY.		Borehole 6652-BLUE

Borehole co-ordinates		Collar elevation	
Depth to top of test section	16.20 m	Length of test section, L	2.7 m
Depth of static water level, H_w	6.09 m	Radius of borehole, r	m
Excess head, h_e	6.09 m	Radius of standpipe or casing, r_c 0.02	m

Time, T (min)	0.68	1.45	2.25	3.08	4.88	6.88	9.23	11.93	15			0			
Depth to water, h_w (m)	0.25	0.5	0.75	1.00	1.50	2.0	2.5	3.0	3.48			0			
Excess head, $h_t = H_w - h_w$ (m)	5.84	5.59	5.34	5.09	4.59	4.09	3.59	3.09	2.61			6.09			
h_t / h_e	0.96	0.92	0.88	0.84	0.75	0.67	0.59	0.51	0.43			1.00			

Head - time graph (slope of graph is S)





Calculations

Permeability $k = 0.133\, S \left(\frac{r_c^2}{L}\right)$ m/sec.

$S = \dfrac{\log_{10}\left(\frac{1.0}{0.43}\right)}{15} = 2.44 \times 10^{-2}$

$k = 4.81 \times 10^{-7}$ m/s

APPENDIX 5: Consolidation test data

NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED Hostel Subsidence Sample No(s): 6651-6.08
Sampling date: 8.1.85 Tested by: P. Kelsey
Sampling location: BH 6651 Date: 15.2.85-1.3.85
Sampling depth: 6.08 Checked by: P. Kelsey
Ground surface elevation: Date: 23.12.85
Water-table elevation: 12.70

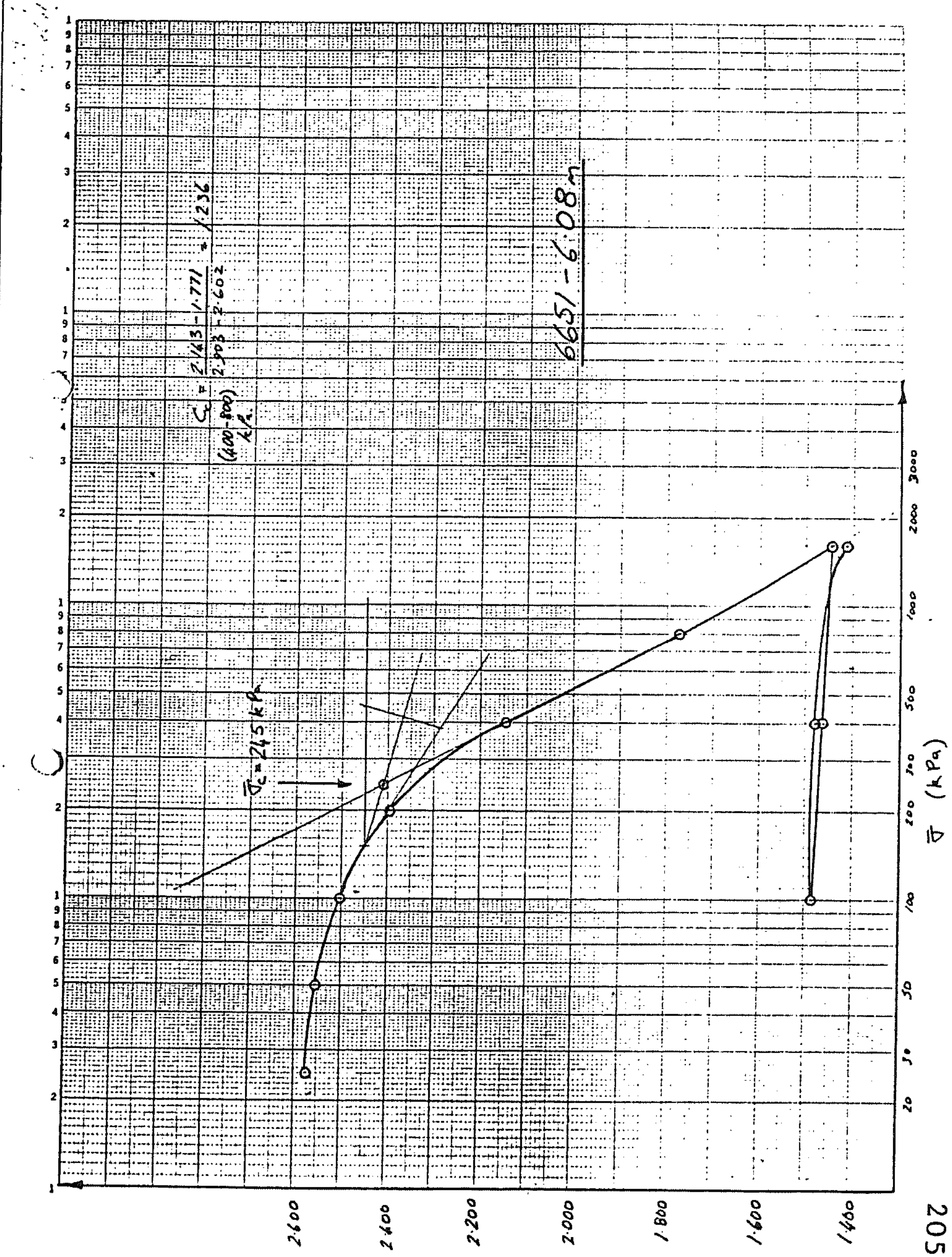
Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 24 hours/~~minutes~~
Specimen No.: 3
Cell No.: 3 Diameter of ring (D) 76.20 mm
Machine No.: 3 Height of ring 19.06 mm
Ring No.: 5 (OSS) Area of ring (A) = $\frac{\pi D^2}{4}$ 4560.37 mm²
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.75 t/m³

Stage:			Initial	Final
Measured thickness of specimen (H)		mm	H_i 18.94	H_f 13.03
Mass of ring + watch glass + wet specimen		g	M_3 256.616	M_4 235.123
Mass of ring + watch glass + dry specimen	M_5	g		197.908
Mass of ring	M_1	g	93.047	93.047
Mass of watch glass	M_2	g	38.740	38.684
Mass of dry specimen	$M_s = M_5 - M_1 - M_2$	g		66.177
Mass of water		g	$M_3 - M_5$ 58.04	$M_4 - M_5$ 37.22
Water content w		%	w_i 86.9	w_f 56.2
Dry density $\rho_d = \frac{M_s}{H \times A}$		t/m³	ρ_{di} 0.77	ρ_{df} 1.11
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$		mm		5.277
Voids ratio $e = \frac{H - H_s}{H_s}$			e_i 2.589	e_f 1.469
Degree of saturation $S = \frac{\rho_s w}{e}$			S_i 92.3	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.096	18.844		13.567	2.571
50		0.092	18.752		13.475	2.554
100		0.280	18.472		13.195	2.501
200		0.558	17.914		12.637	2.395
400		1.330	16.584		11.307	2.143
800		1.964	14.620		9.343	1.771
1600		1.730	12.890		7.613	1.443
400		0.090	12.980		7.703	1.460
100		0.113	13.093		7.816	1.481
400		0.069	13.024		7.747	1.468
1600		0.290	12.734		7.457	1.413
25		0.299	13.033		7.756	1.470

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED HOSTEL SUBSIDENCE Sample No(s): 6651-6.45
Sampling date: 8.1.85 Tested by: P. KELSEY
Sampling location: BH 6651 Date: 13.2.85 - 1.3.85
Sampling depth: 6.45 Checked by: P. KELSEY
Ground surface elevation: 21.73 Date: 23.12.85
Water-table elevation: 12.70

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.:

Cell No.: 2 Diameter of ring (D) 76.28 mm

Machine No.: 2 Height of ring 19.09 mm

Ring No.: 6 Area of ring $(A) = \frac{\pi D^2}{4}$ 4570 mm²

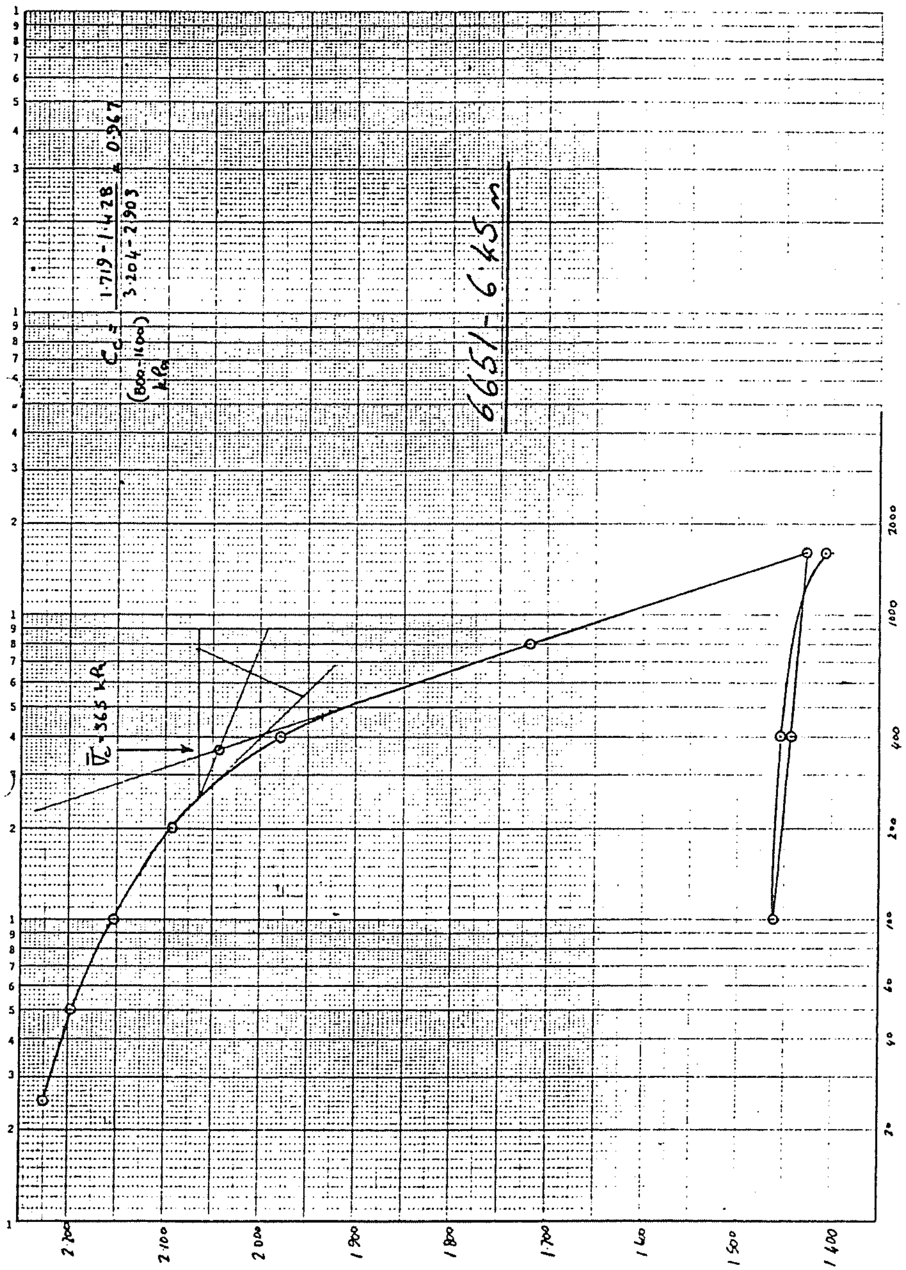
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.75 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 18.90	H_f 14.27
Mass of ring + watch glass + wet specimen	g	M_3 264.005	M_4 247.955
Mass of ring + watch glass + dry specimen M_5	g		207.406
Mass of ring M_1	g	94.567	94.567
Mass of watch glass M_2	g	38.680	39.901
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		72.938
Mass of water	g	$M_3 - M_5$ 57.82	$M_4 - M_5$ 40.55
Water content w	%	w_i 79.3	w_f 55.6
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.85	ρ_{df} 1.12
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	5.804	5.804
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2.256	e_f 1.459
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 97	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.179	18.721		12.917	2.226
50		0.169	18.552		12.748	2.196
100		0.246	18.306		12.502	2.154
200		0.352	17.954		12.150	2.093
400		0.666	17.288		11.484	1.979
800		1.508	15.780		9.976	1.719
1600		1.690	14.090		8.286	1.428
400		0.087	14.177		8.373	1.443
100		0.107	14.284		8.480	1.461
400		0.041	14.243		8.439	1.454
1600		0.263	13.980		8.176	1.409
0		0.285	14.265		8.461	1.458

* Delete the inappropriate words.

GORMACK GRAPH PAPERS CHRISTCHURCH N Z D411Y Log 4 cycle x mm



NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: N.Z.E.D HOSTEL SUBSIDENCE | Sample No(s): 6651 - 6.68 vert

Sampling date: 8.1.85 | Tested by: P. Kelsey

Sampling location: BH6651 | Date: 21.4.85 – 10.6.85

Sampling depth: 6.58m | Checked by: P. Kelsey

Ground surface elevation: | Date: 21.9.85

Water-table elevation: 12.70m

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 7 days ~~hours/minutes~~

Specimen No.:

Cell No.: 3 | Diameter of ring (D) 76.09 mm

Machine No.: 3 | Height of ring 18.49 mm

Ring No.: 3 BRASS | Area of ring (A) = $\frac{\pi D^2}{4}$ 4547.21 mm²

Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.75 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 18.360	H_f 14.503
Mass of ring + watch glass + wet specimen	g	M_3 217.819	M_4 239.542
Mass of ring + watch glass + dry specimen M_5	g		198.191
Mass of ring M_1	g	87.575	87.575
Mass of watch glass M_2	g	—	37.807
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		72.809
Mass of water	g	$M_3 - M_5$ 57.435	$M_4 - M_5$ 41.351
Water content w	%	w_i 78.9	w_f 56.8
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.872	ρ_{df} 1.104
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	5.822	5.822
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2.153	e_f 1.491
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 100	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.130	18.230			2.131
50		0.097	18.133			2.115
100		0.193	17.940			2.081
200		0.342	17.598			2.023
400		0.705	16.893			1.902
800		1.256	15.637			1.686
1600		1.591	14.046			1.413
400		-0.076	14.122			1.426
100		-0.117	14.239			1.446
25		-0.118	14.357			1.466
0		-0.146	14.503			1.491

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.

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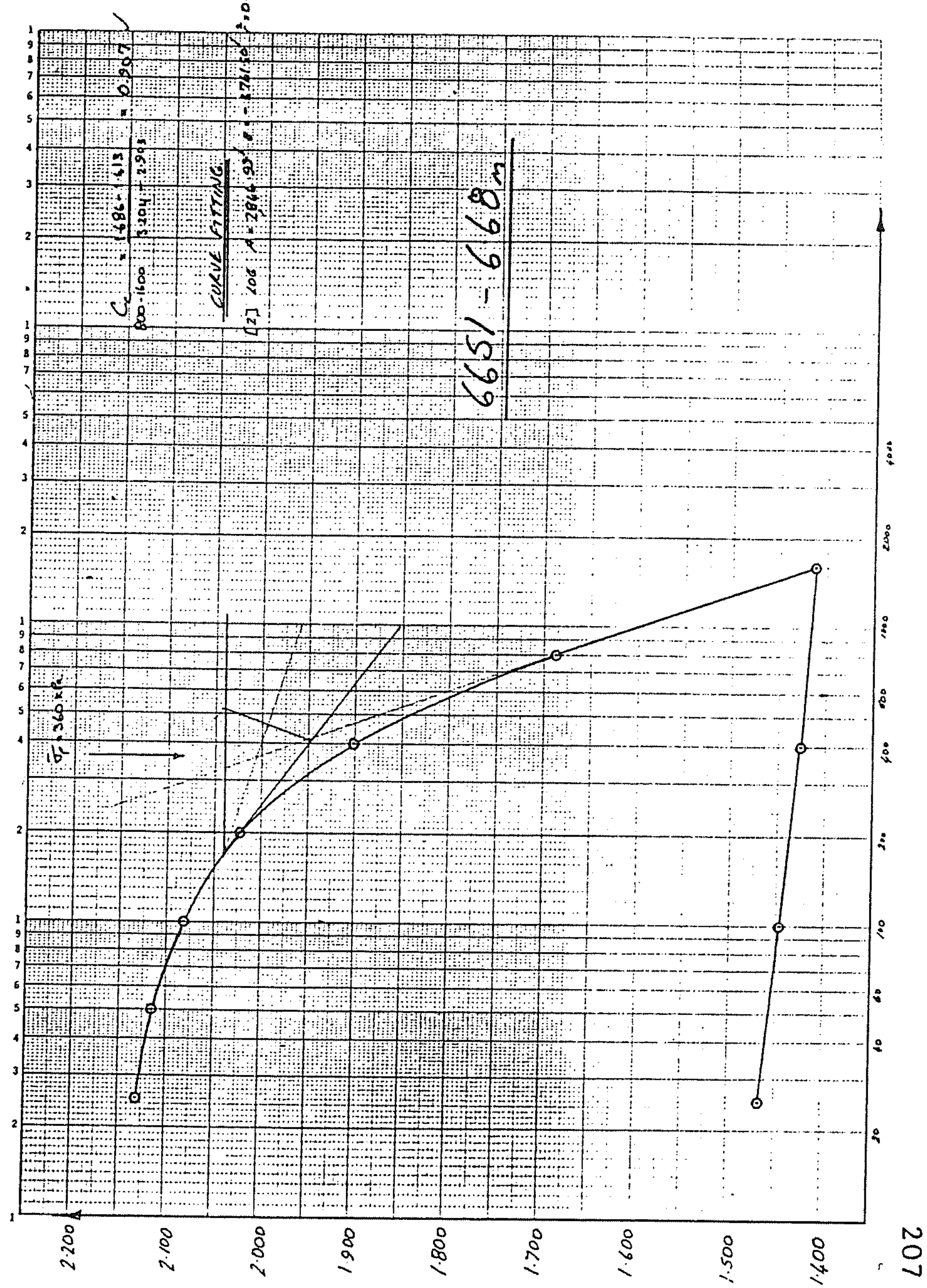
6651 - 6.68



FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED Hostel Subsidence — Sample No(s): 6651-7.21
Sampling date: 8.1.85 — Tested by: P. KELSEY
Sampling location: BH 6651 — Date: 13.2.85-1.3.85
Sampling depth: 7.21 m — Checked by: P. KELSEY
Ground surface elevation: 21.73 — Date: 23.12.85
Water-table elevation: 12.70

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.: 1

Cell No.: 1 — Diameter of ring (D) 76.28 mm

Machine No.: 1 — Height of ring 18.98 mm

Ring No.: 4 — Area of ring (A) $= \frac{\pi D^2}{4}$ 4569.95 mm²

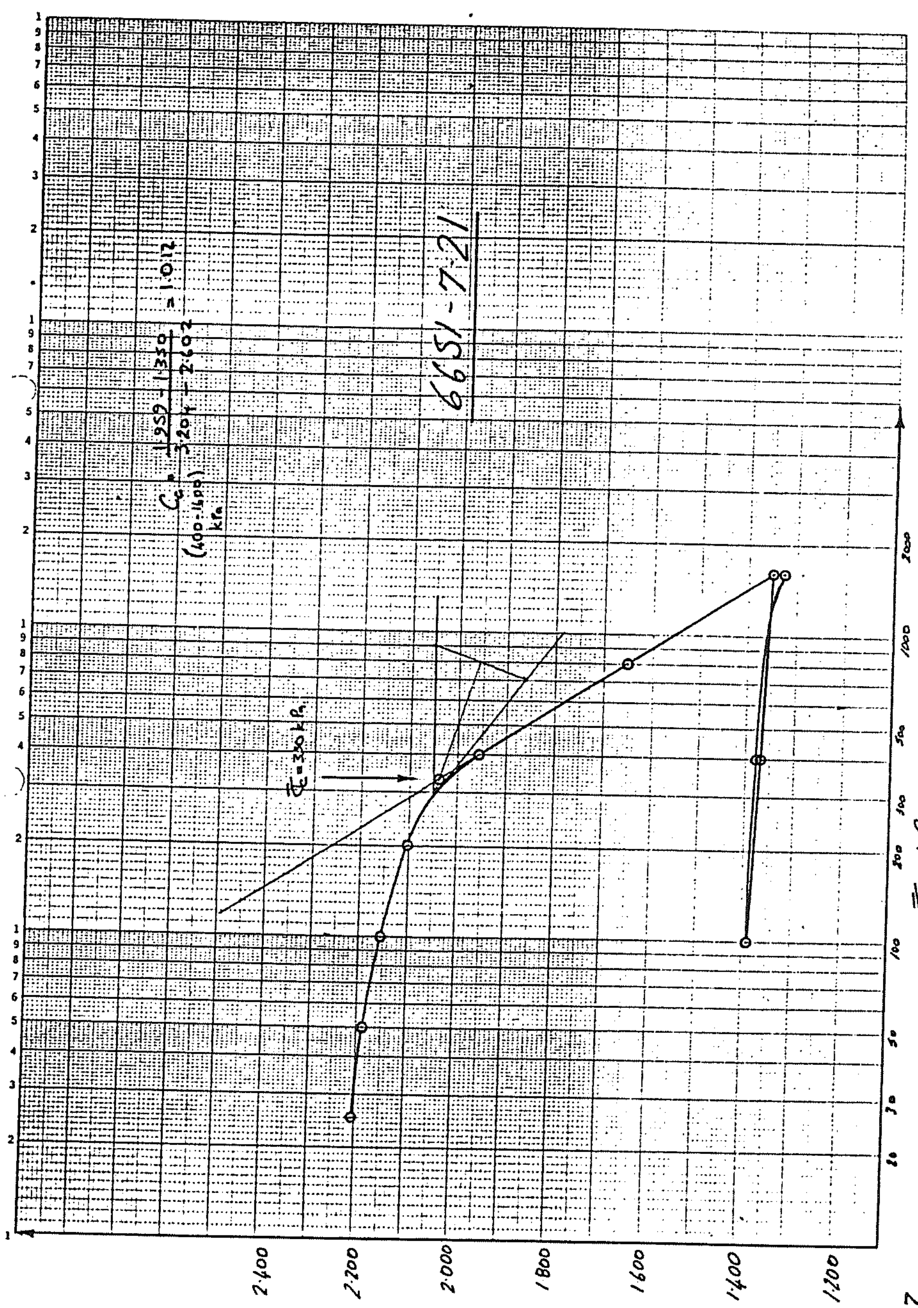
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.66 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 18.70	H_f 13.85
Mass of ring + watch glass + wet specimen	g	M_3 265.634	M_4 240.842
Mass of ring + watch glass + dry specimen M_5	g		200.683
Mass of ring M_1	g	92.293	92.293
Mass of watch glass M_2	g	38.747	37.908
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		70.482
Mass of water	g	$M_3 - M_5$ 61.112	$M_4 - M_5$ 40.159
Water content w	%	w_i 91	w_f 57
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.825	ρ_{df} 1.11
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	5.798	5.798
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2.225	e_f 1.389
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 100	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.118	18.582		12.784	2.205
50		0.096	18.486		12.688	2.188
100		0.194	18.292		12.494	2.155
200		0.314	17.978		12.180	2.101
400		0.821	17.157		11.359	1.959
800		1.776	15.381		9.583	1.653
1600		1.757	13.624		7.826	1.350
400		0.103	13.727		7.929	1.368
100		0.133	13.860		8.062	1.390
400		0.070	13.790		7.992	1.378
1600		0.289	13.501		7.703	1.329
25		0.352	13.853		8.055	1.389

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.

GORMACK GRAPH PAPERS CHRISTCHURCH N Z D411Y Log 4 cycle x mm



NZS 4402
Part 2P : 1981

FORM 21
DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

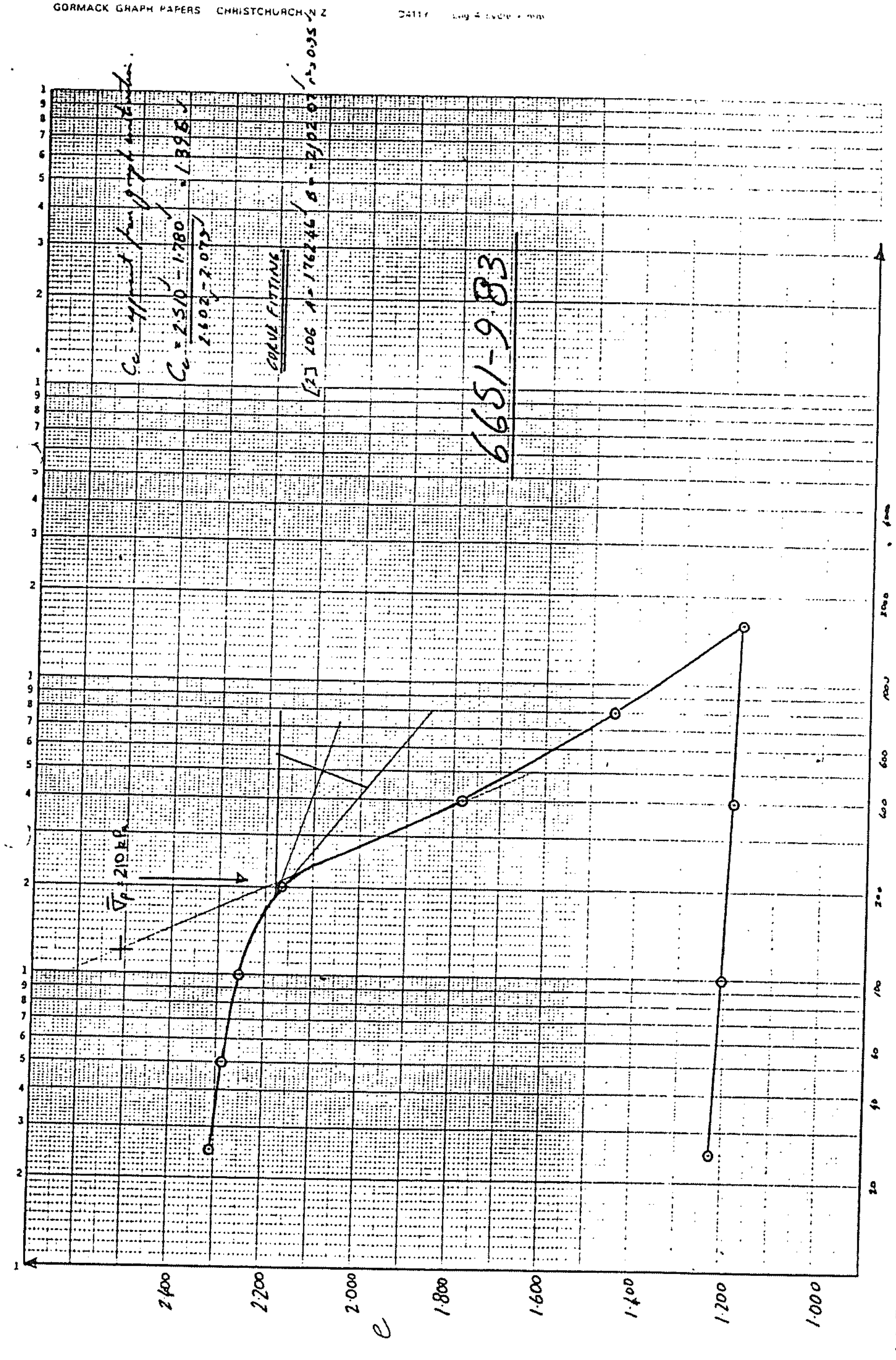
Job: NZED. HOSTEL SUBSIDENCE — Sample No(s): 6651-9.83m
Sampling date: 8.1.85 — Tested by: P. Kelsey
Sampling location: BH6651 — Date: 21-4-85 — 10-6-85
Sampling depth: 9.82m — Checked by: P. Kelsey.
Ground surface elevation: — Date: 21-9-85
Water-table elevation:
Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 7 days ~~hours/minutes~~
Specimen No.:
Cell No.: 1 — Diameter of ring (D) 76.02 mm
Machine No.: 1 — Height of ring 19.14 mm
Ring No.: 6 OSS — Area of ring (A) = $\frac{\pi D^2}{4}$ 4538.85 mm²
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.65 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 18.980	H_f 12.785
Mass of ring + watch glass + wet specimen	g	M_3 223.581	M_4 237.349
Mass of ring + watch glass + dry specimen M_5	g		202.407
Mass of ring M_1	g	94.563	94.563
Mass of watch glass M_2	g	—	39.362
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		68.482
Mass of water	g	$M_3 - M_5$ 60.536	$M_4 - M_5$ 34.942
Water content w	%	w_i 88.4	w_f 51.0
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.795	ρ_{df} 1.180
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	5.694	5.694
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2.334	e_f 1.246
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 100	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.142	18.838			2.309
50		0.116	18.722			2.288
100		0.195	18.527			2.254
200		0.503	18.024			2.166
400		2.195	15.829			1.780
800		1.877	13.952			1.450
1600		1.575	12.377			1.174
400		-0.074	12.451			1.187
100		-0.106	12.557			1.205
25		-0.105	12.662			1.224
0		-0.123	12.785			1.246

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



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NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED HOSTEL SUBSIDENCE
Sampling date: 8-1-85
Sampling location: BH6651
Sampling depth: 10.50m
Ground surface elevation:
Water-table elevation:
Test details:*

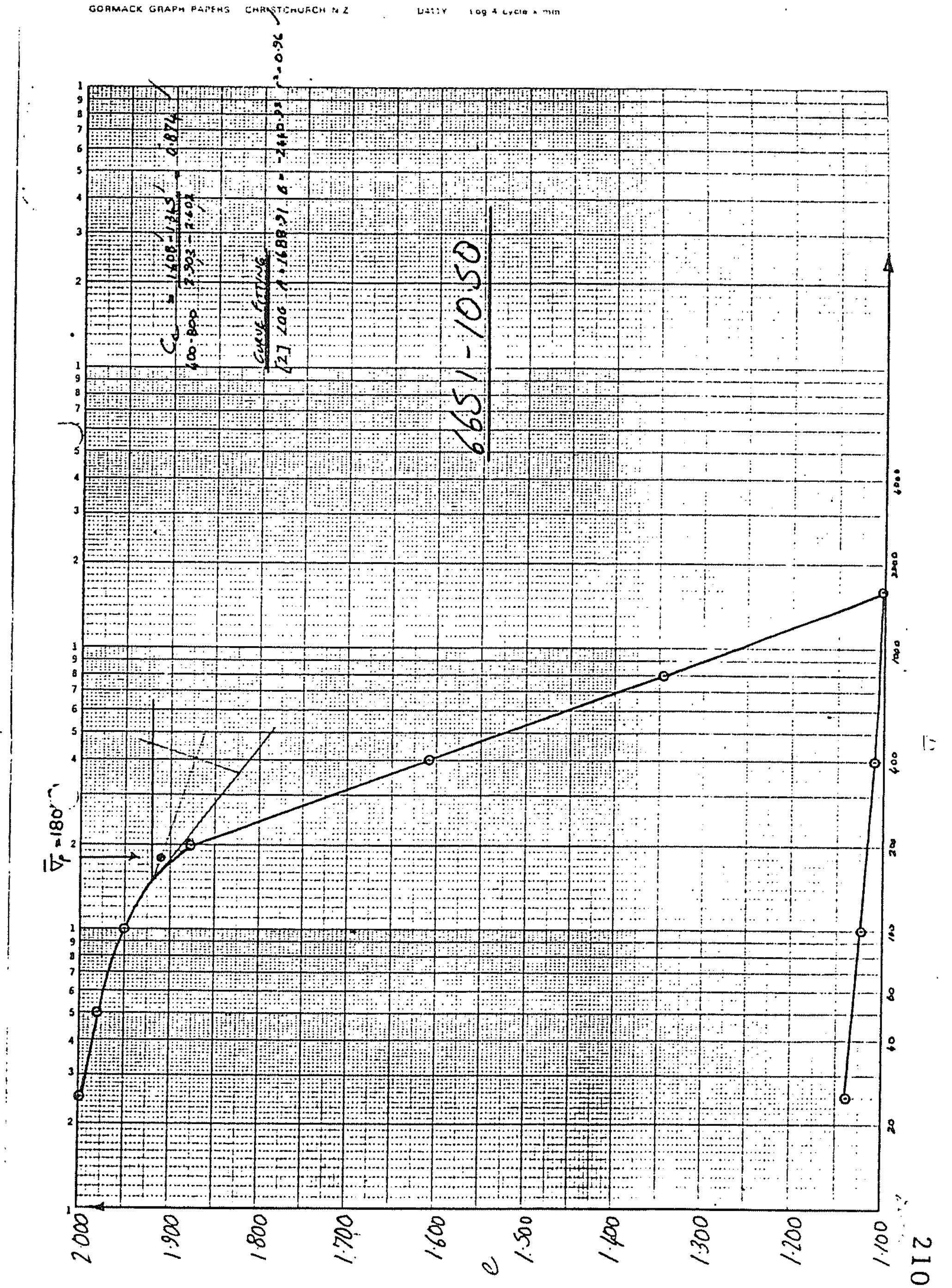
Sample No(s): 6651-10-50
Tested by: P. Kelsey
Date: 21-4-85 — 10-6-85
Checked by: P. Kelsey
Date: 21-9-85

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 7 days ~~hours/minutes~~
Specimen No.:
Cell No.: 2 — Diameter of ring (D) 76.20 mm
Machine No.: 2 — Height of ring 19.07 mm
Ring No.: 5 OLD SS — Area of ring (A) = $\frac{\pi D^2}{4}$ 4560.37 mm²
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.59 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19.113	H_f 13.506
Mass of ring + watch glass + wet specimen	g	M_3 225.057	M_4 240.485
Mass of ring + watch glass + dry specimen M_5	g		204.938
Mass of ring M_1	g	93.052	93.052
Mass of watch glass M_2	g	—	37.323
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		74.563
Mass of water	g	$M_3 - M_5$ 57.442	$M_4 - M_5$ 35.547
Water content w	%	w_i 77.0	w_f 47.7
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.855	ρ_{df} 1.211
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	6.313	6.313
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2.028	e_f 1.139
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 98.3	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.180	18.933			1.999
50		0.123	18.810			1.980
100		0.185	18.625			1.950
200		0.461	18.164			1.877
400		1.701	16.463			1.608
800		1.662	14.801			1.345
1600		1.523	13.278			1.103
400		-0.044	13.322			1.110
100		-0.081	13.403			1.123
25		-0.103	13.506			1.139
0		—				

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



NZS 4402
Part 2P : 1981

FORM 21
DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: N.Z.E.Q. Hostel Subsidence — Sample No(s): 6651-12.85
Sampling date: 8.1.85 — Tested by: P. Kelsey
Sampling location: BH. 6651 — Date: 2.5.85 - 18.5.85
Sampling depth: 12.85m — Checked by: P. Kelsey
Ground surface elevation: 21.73m — Date: 17.7.85
Water-table elevation: 18.70m
Test details:*

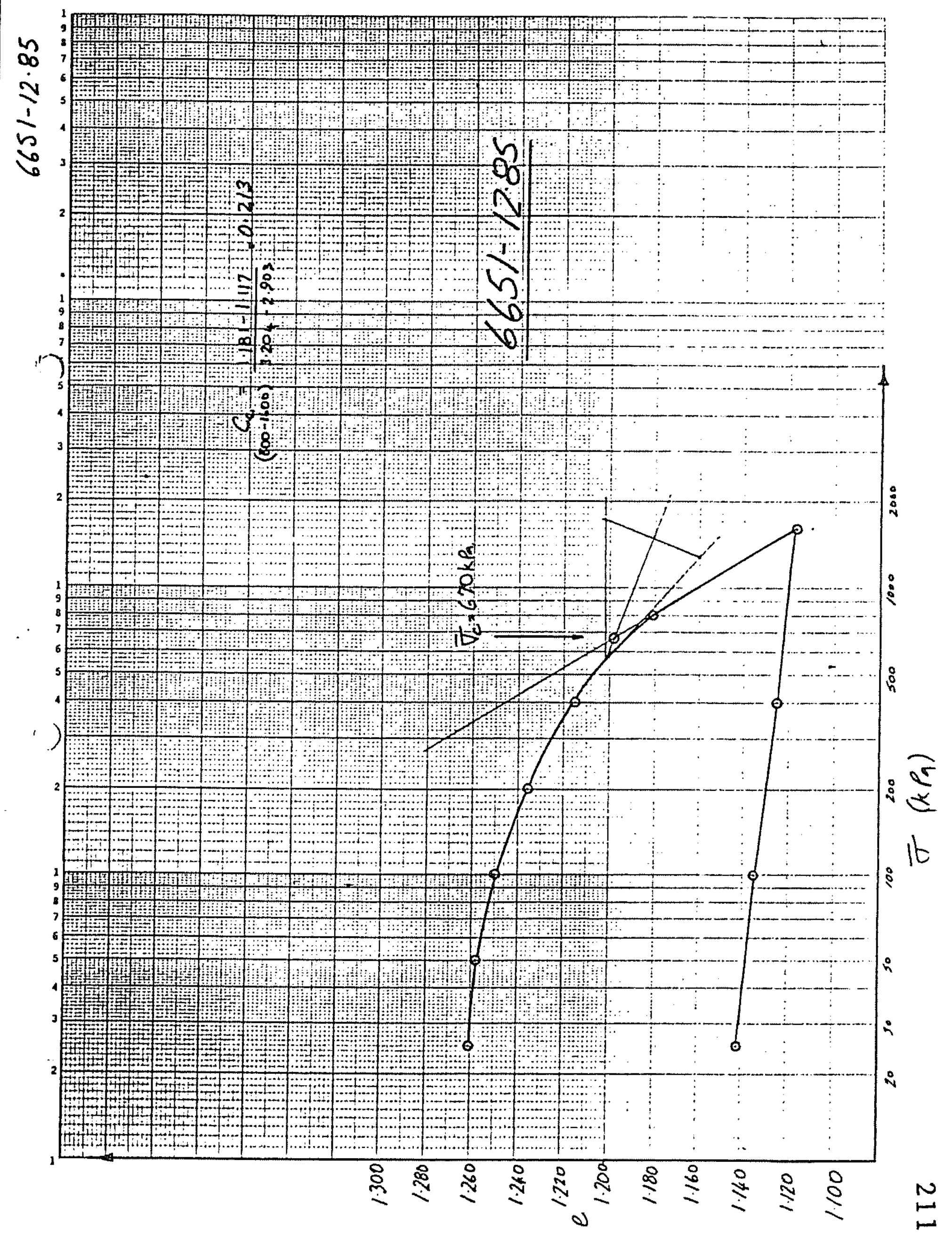
Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 24 hours/~~minutes~~
Specimen No.:
Cell No.: 5 — Diameter of ring (D) 76.28 mm
Machine No.: 5 — Height of ring 19.15 mm
Ring No.: 7 (brass) — Area of ring (A) = $\frac{\pi D^2}{4}$ 4569.95 mm^2
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.46 t/m^3

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19.080	H_f 18.203
Mass of ring + watch glass + wet specimen	g	M_3 273.690	M_4 271.654
Mass of ring + watch glass + dry specimen M_5	g		226.327
Mass of ring M_1	g	92.868	92.868
Mass of watch glass M_2	g	39.396	38.992
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		94.467
Mass of water	g	$M_3 - M_5$ 46.959	$M_4 - M_5$ 45.327
Water content w	%	w_i 50	w_f 48
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m^3	ρ_{di} 1.08	ρ_{df} 1.14
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	8.403	8.403
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 1.271	e_f 1.166
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 97	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.080	19.00		10.60	1.261
50		0.033	18.97		10.57	1.258
100		0.061	18.91		10.51	1.250
200		0.118	18.79		10.39	1.236
400		0.174	18.61		10.21	1.215
800		0.282	18.33		9.93	1.181
1600		0.547	17.79		9.39	1.117
400		0.068	17.86		9.46	1.125
100		0.078	17.94		9.54	1.135
25		0.059	18.00		9.60	1.142

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.

GORMACK GRAPH PAPERS CHRISTCHURCH N Z D411Y Log 4 cycle × mm



NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: N.Z.E.D. Hostel Subsidence
Sampling date: 8.1.85
Sampling location: BH 6651
Sampling depth: 13.59
Ground surface elevation: 21.73m
Water-table elevation: 12.70m

Sample No(s): 6651-13.59
Tested by: P Kelsey
Date: 2.5.85-18.5.85
Checked by: P Kelsey
Date: 17.7.85

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.:

Cell No.: 6 Diameter of ring (D) 76.28 mm

Machine No.: 6 Height of ring 19.06 mm

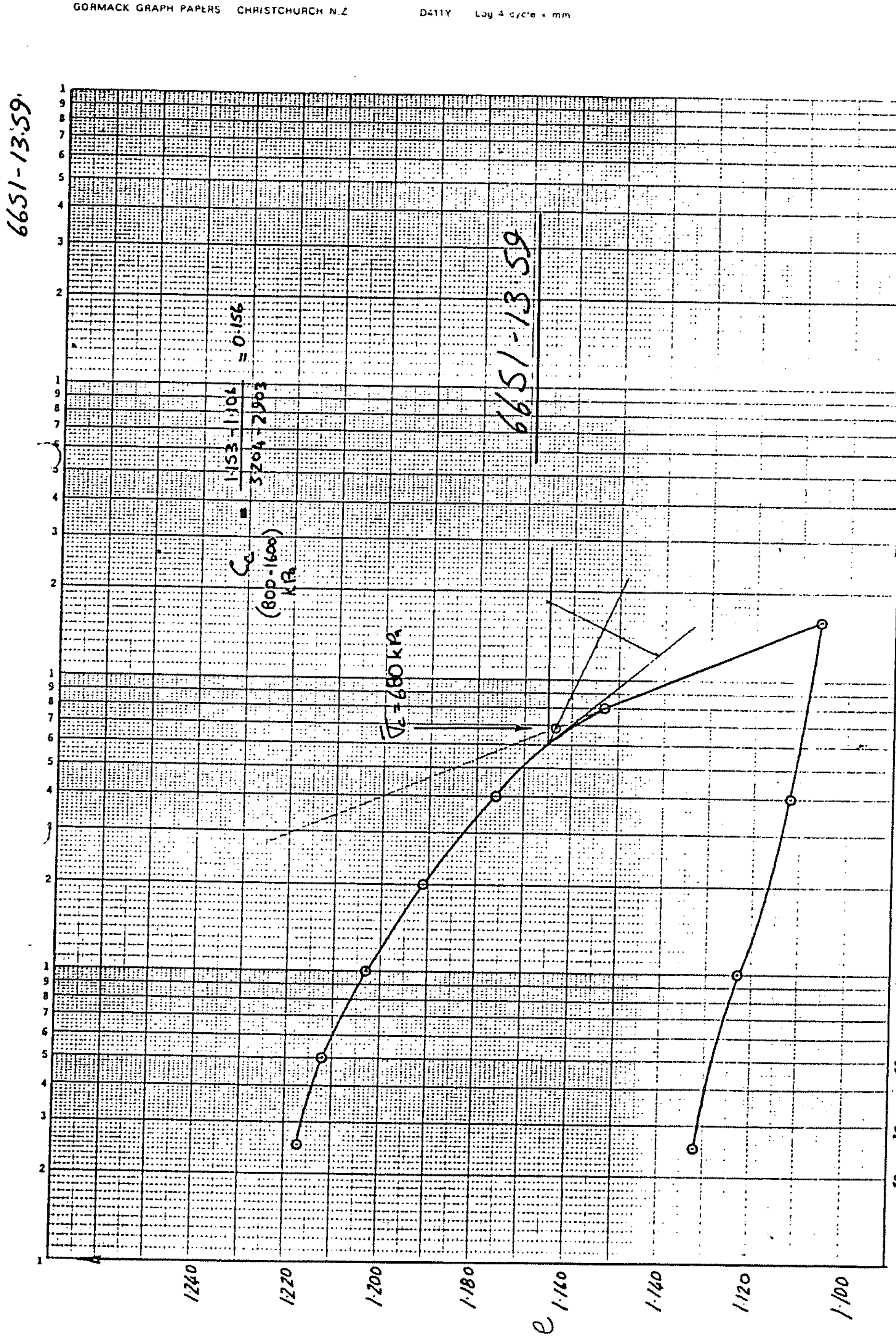
Ring No.: 1 old stainless steel Area of ring (A) = $\frac{\pi D^2}{4}$ 4569.95 mm^2

Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.43 t/m^3

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19.060	H_f 18.313
Mass of ring + watch glass + wet specimen	g	M_3 273.691	M_4 271.612
Mass of ring + watch glass + dry specimen M_5	g		226.198
Mass of ring M_1	g	92.301	92.301
Mass of watch glass M_2	g	38.984	38.593
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		95.304
Mass of water	g	M_3-M_5 47.102	M_4-M_5 45.414
Water content w	%	w_i 49.4	w_f 47.7
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m^3	ρ_{di} 1.09	ρ_{df} 1.14
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	8.582	8.582
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 1.221	e_f 1.134
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 98	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H ($H_i - \Delta H$)	% change thickness $\frac{H_i - H}{H_i}$	Height of voids ($H - H_s$)	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.032	19.028		10.45	1.217
50		0.048	18.980		10.40	1.212
100		0.073	18.907		10.33	1.203
200		0.103	18.804		10.22	1.191
400	-	0.133	18.671		10.09	1.176
800		0.196	18.475		9.89	1.163
1600		0.398	18.077		9.50	1.106
400		0.066	18.143		9.56	1.114
100		0.076	18.219		9.64	1.123
25		0 080	18.299		9.72	1.132

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: N.Z.E.D. Hostel Subsidence	Sample No(s): 6651-19.30
Sampling date: 8.1.85	Tested by: P. Kelsey
Sampling location: BH 6651	Date: 22.5.85-31.5.85
Sampling depth: 19.30 m	Checked by: P. Kelsey
Ground surface elevation: 21.73 m	Date: 17.7.85
Water-table elevation: 12.70 m	

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.:

Cell No.: 6 Diameter of ring (D) 76.12 mm

Machine No.: 6 Height of ring 19.16 mm

Ring No.: 11 Area of ring $(A) = \frac{\pi D^2}{4}$ 4550.8 mm^2

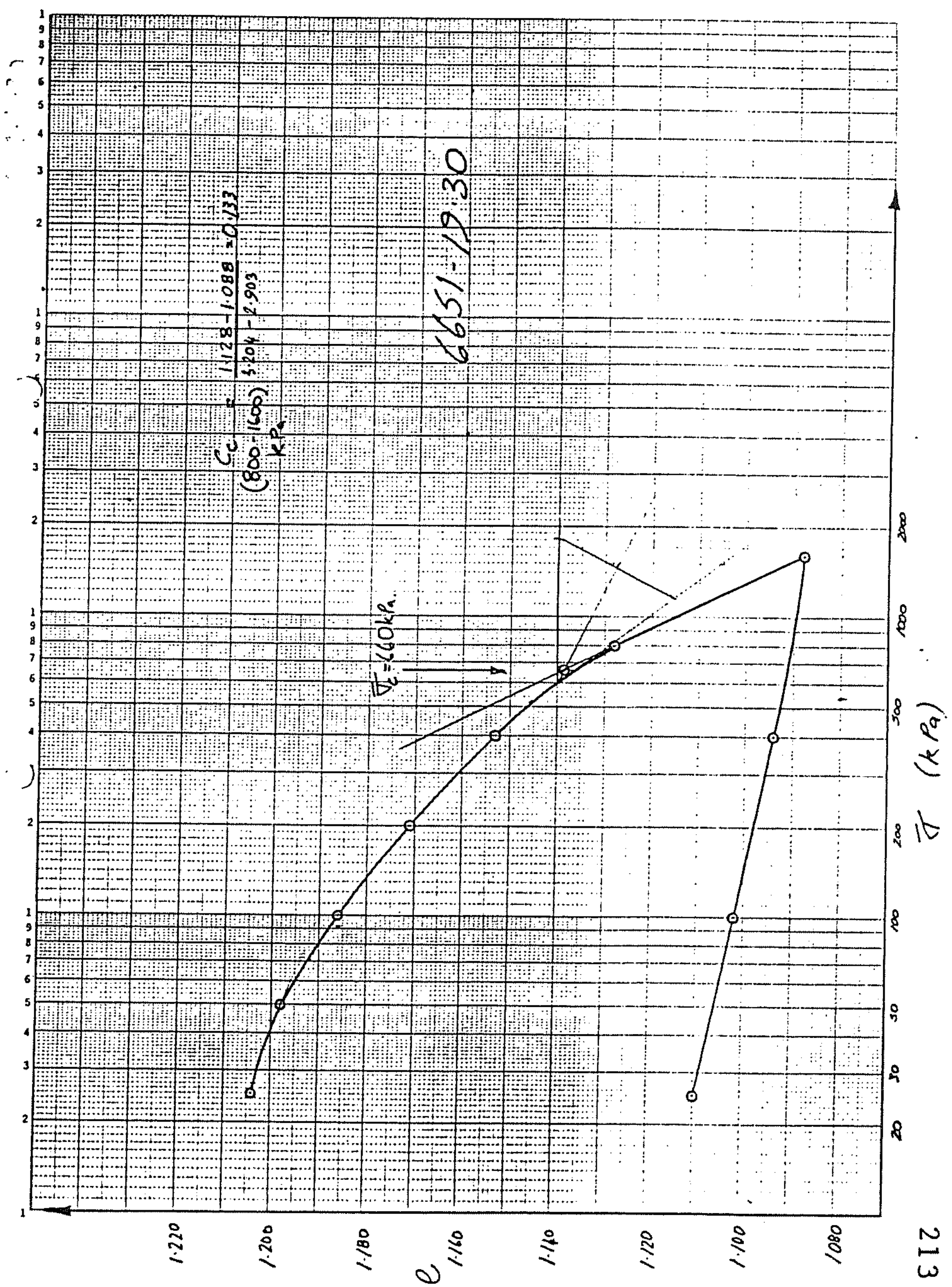
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.67 t/m^3

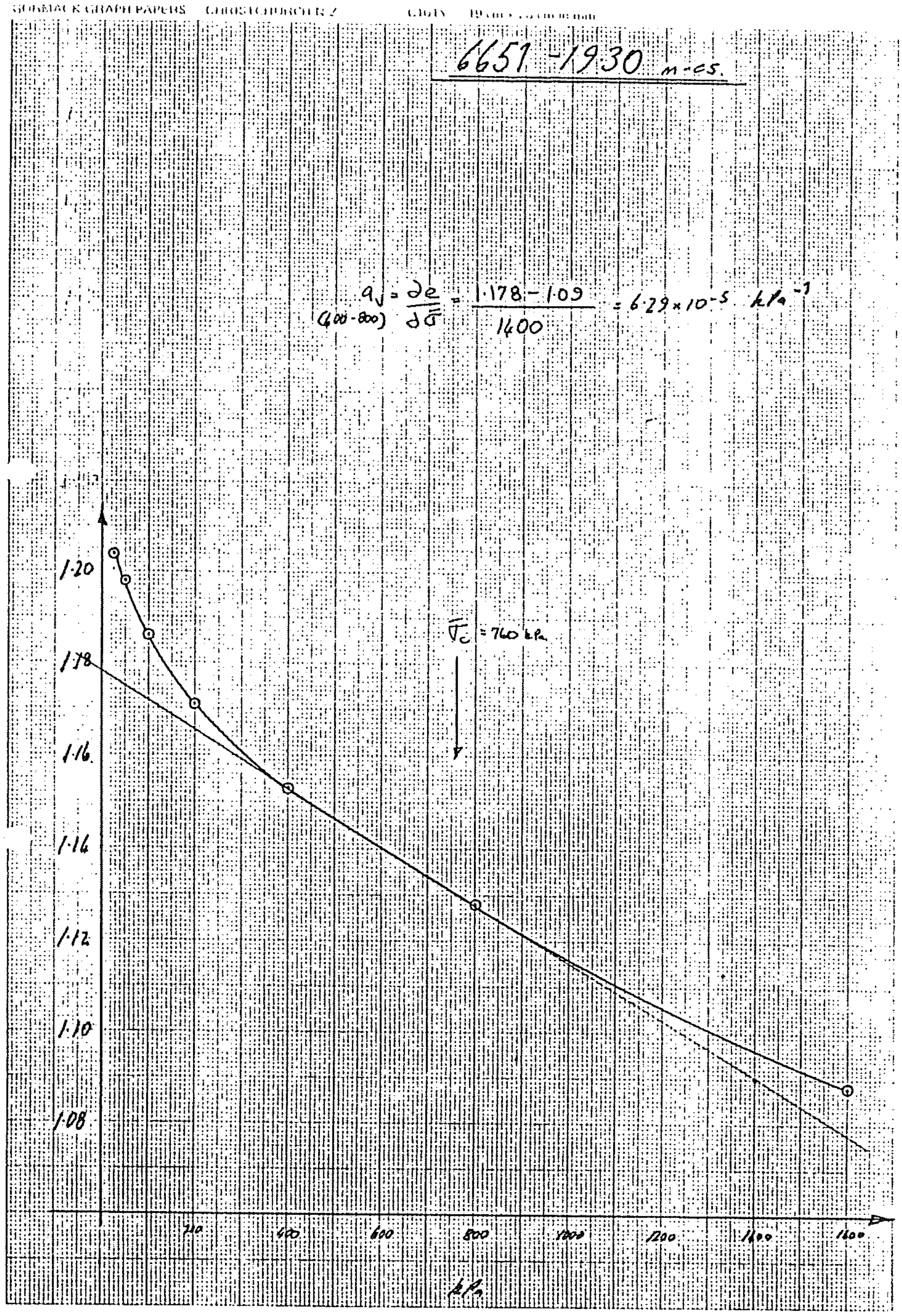
Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 18.89	H_f 18.00
Mass of ring + watch glass + wet specimen	g	M_3 268.584	M_4 270.757
Mass of ring + watch glass + dry specimen M_5	g		276.692
Mass of ring M_1	g	91.26	91.26
Mass of watch glass M_2	g	37.331	39.359
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		95.873
Mass of water	g	M_3-M_5 44.120	M_4-M_5 44.265
Water content w	%	w_i 46	w_f 46
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m^3	ρ_{di} 1.12	ρ_{df} 1.17
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	8.529	8.529
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 1.215	e_f 1.110
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 93.5	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.090	18.800		10.271	1.204
50		0.056	18.744		10.215	1.198
100		0.102	18.642		10.113	1.186
200		0.128	18.514		9.985	1.171
400		0.154	18.360		9.831	1.153
800		0.213	18.147		9.618	1.128
1600		0.336	17.811		9.282	1.088
400		0.050	17.861		9.332	1.094
100		0.069	17.930		9.401	1.102
25		0.066	17.996		9.467	1.110

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.

GORMACK GRAPH PAPERS CHRISTCHURCH N.Z




6651 - 1930 m-es.
$a_v = \frac{\partial e}{\partial \bar{\sigma}} = \frac{1.178 - 1.09}{1400} = 6.29 \times 10^{-5}\ kPa^{-1}$
(400-800)
$\bar{\sigma}_c = 760$ kPa
e
1.20
1.18
1.16
1.14
1.12
1.10
1.08
200
400
600
800
1000
1200
1400
1600
kPa

NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: N.Z.E.I. HOSTEL SUBSIDENCE — Sample No(s): 6651 – 22.55 vert

Sampling date: 9.1.85 — Tested by: P. KELSEY

Sampling location: BH 6651 — Date: 19.6.86 – 2.7.86

Sampling depth: 22.55 m — Checked by: P. KELSEY

Ground surface elevation: 21.73 m — Date: 19.9.86

Water-table elevation: 12.70 m

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.: 1

Cell No.: 1 — Diameter of ring (D) 76.10 mm

Machine No.: 1 — Height of ring 18.57 mm

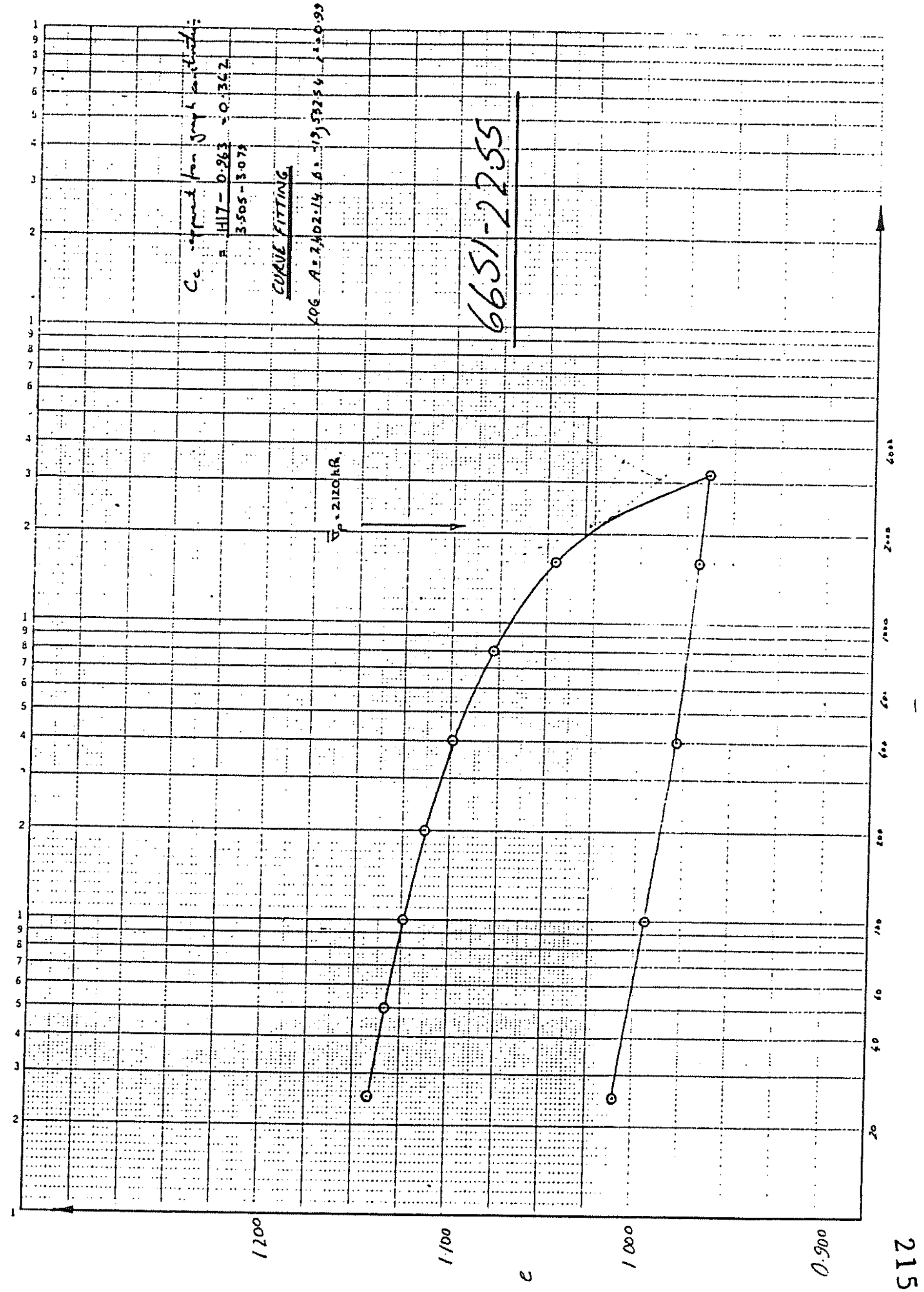
Ring No.: 6 NEW SS — Area of ring (A) = $\frac{\pi D^2}{4}$ 4548.4/mm²

Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.44 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 18.603	H_f 17.470
Mass of ring + watch glass + wet specimen	g	M_3 263.290	M_4 263.349
Mass of ring + watch glass + dry specimen M_5	g		219.439
Mass of ring M_1	g	85.279	85.279
Mass of watch glass M_2	g	37.352	38.732
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		95.428
Mass of water	g	M_3-M_5 45.231	M_4-M_5 43.910
Water content w	%	w_i 47.4	w_f 46.0
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 1.128	ρ_{df} 1.201
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	8.599	8.599
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 1.163	e_f 1.032
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 99.4	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.182	18.421			1.142
50		0.075	18.346			1.133
100		0.085	18.261			1.124
200		0.093	18.168			1.113
400		0.125	18.043			1.098
800		0.174	17.869			1.078
1600		0.274	17.595			1.046
2200		0.715	16.880			0.963
1600		-0.039	16.919			0.968
400		-0.101	17.020			0.979
100		-0.124	17.144			0.994
25		-0.140	17.284			1.010
0		-0.186	17.470			1.032

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: N.Z.E.D. HOSTEL SUBSIDENCE   Sample No(s): 6651 – 27.85
Sampling date: 8.1.86   Tested by: D. KELSEY
Sampling location: BH 6651   Date: 17.6.85 – 24.6.85
Sampling depth: 27.85 m   Checked by: P. KELSEY
Ground surface elevation: 21.73 m   Date: 19.9.85
Water-table elevation: 12.70 m

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.: 4

Cell No.: 4   Diameter of ring (D) 76.15 mm

Machine No.: 4   Height of ring 19.17 mm

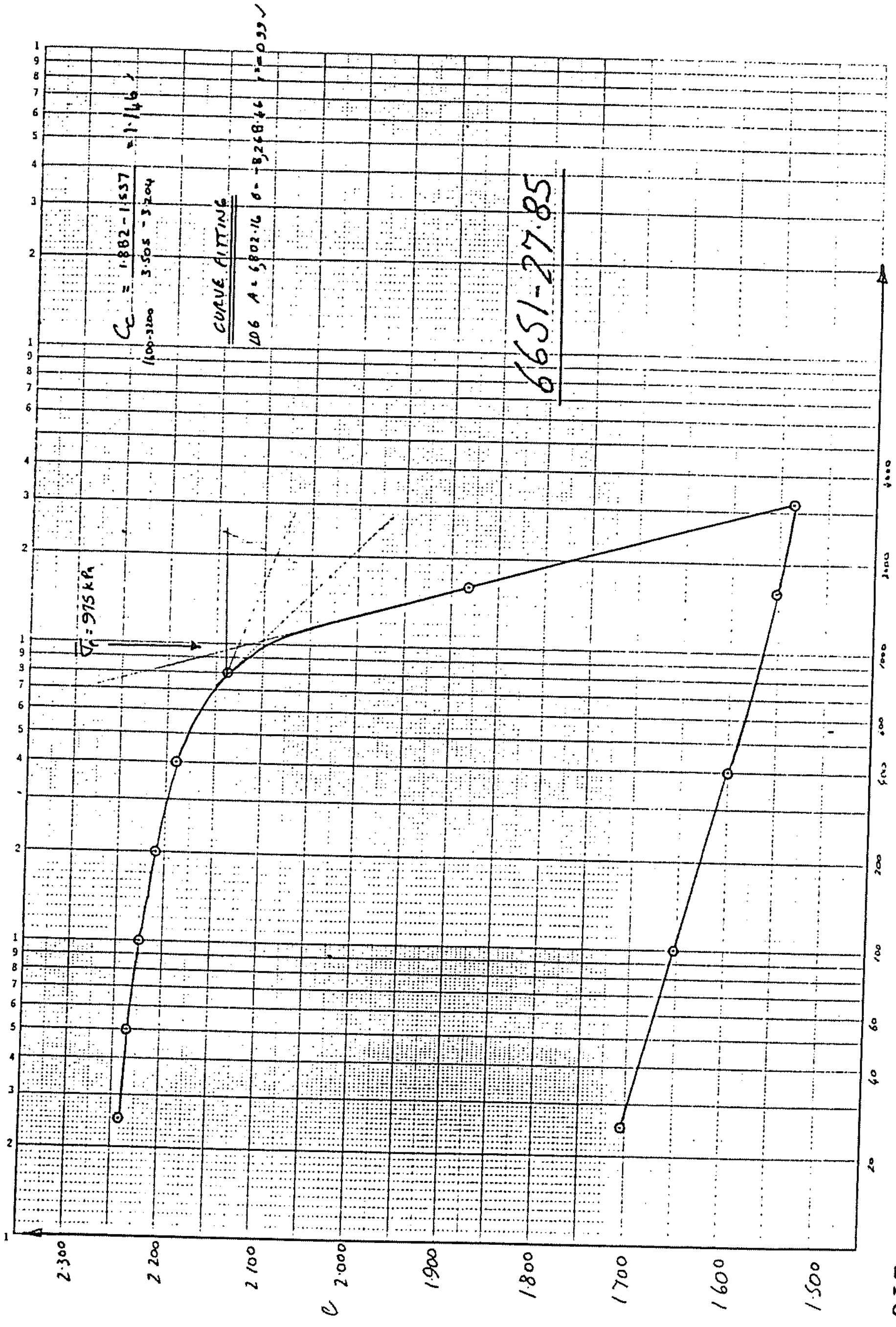
Ring No.: 12 NEW SS   Area of ring (A) = $\frac{\pi D^2}{4}$ 4554.39 mm²

Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.45 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 18.337	H_f 15.662
Mass of ring + watch glass + wet specimen	g	M_3 241.034	M_4 230.296
Mass of ring + watch glass + dry specimen M_5	g		183.958
Mass of ring M_1	g	82.315	82.315
Mass of watch glass M_2	g	39.349	38.652
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		62.991
Mass of water	g	M_3-M_5 56.379	M_4-M_5 46.338
Water content w	%	w_i 89.5	w_f 73.6
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.754	ρ_{df} 0.883
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	5.645	5.645
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2.248	e_f 1.774
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 97.5	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H ($H_i - \Delta H$)	% change thickness $\frac{H_i - H}{H_i}$	Height of voids ($H - H_s$)	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.039	18.298			2.241
50		0.032	18.266			2.236
100		0.060	18.206			2.225
200		0.083	18.123			2.210
400		0.116	18.007			2.190
800		0.293	17.714			2.138
1600		1.443	16.271			1.882
3200		1.951	14.320			1.537
1600		-0.093	14.413			1.553
400		-0.264	14.677			1.600
100		-0.308	14.985			1.654
25		-0.286	15.271			1.705
0		-0.391	15.662			1.774

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZER. HOSTEL SUBSIDENCE — Sample No(s): 6651-28.65m
Sampling date: 8.1.86 — Tested by: P. KELSEY
Sampling location: BH 6551 — Date: 18.6.85 - 3.7.85
Sampling depth: 28.55m — Checked by: P KELSEY
Ground surface elevation: 21.73m — Date: 19.9.85
Water-table elevation: 12.73m

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.: 3

Cell No.: 3 — Diameter of ring (D) 76.31 mm

Machine No.: 3 — Height of ring 19.06 mm

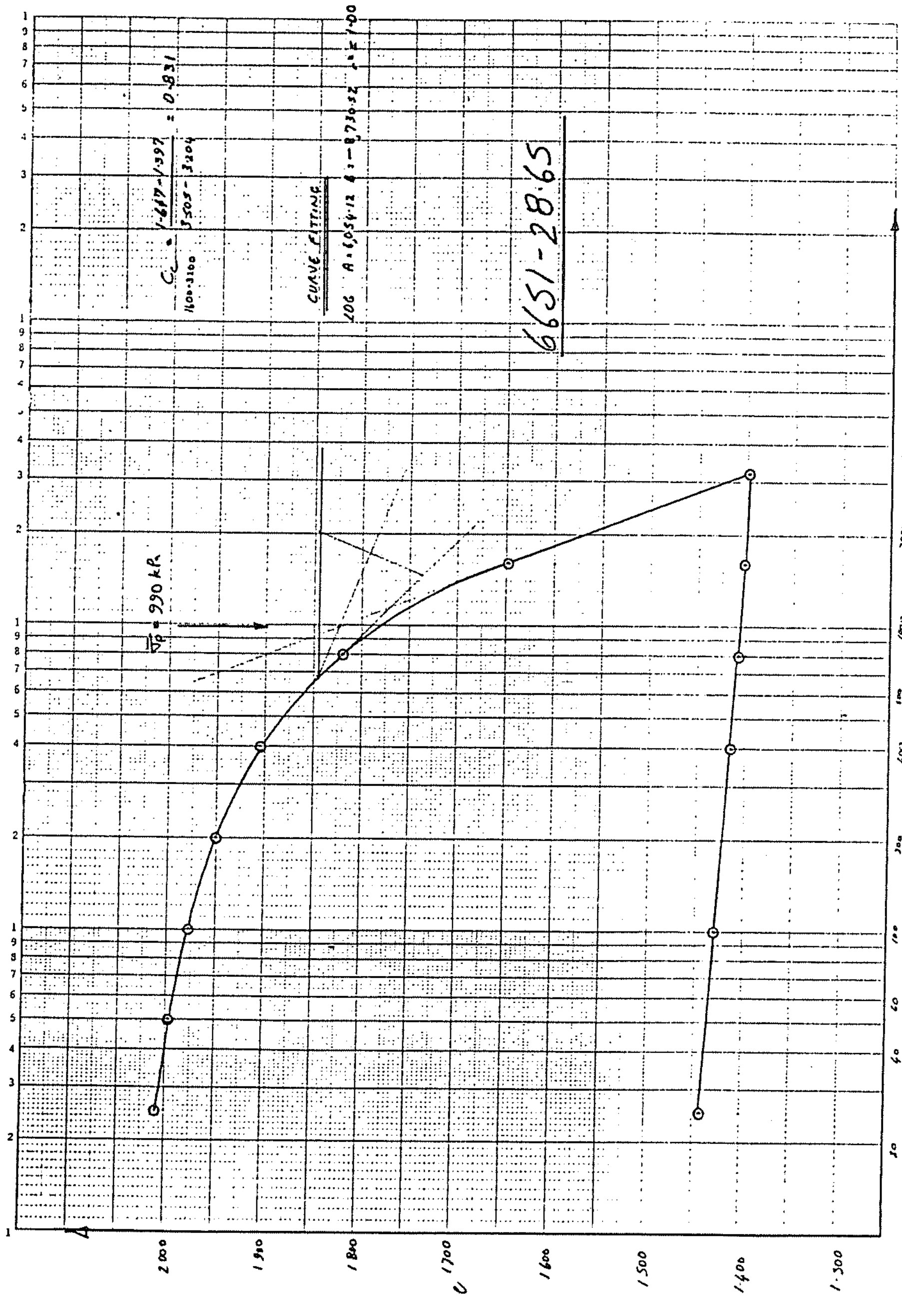
Ring No.: 4 — Area of ring (A) = $\frac{\pi D^2}{4}$ 4573.5 mm²

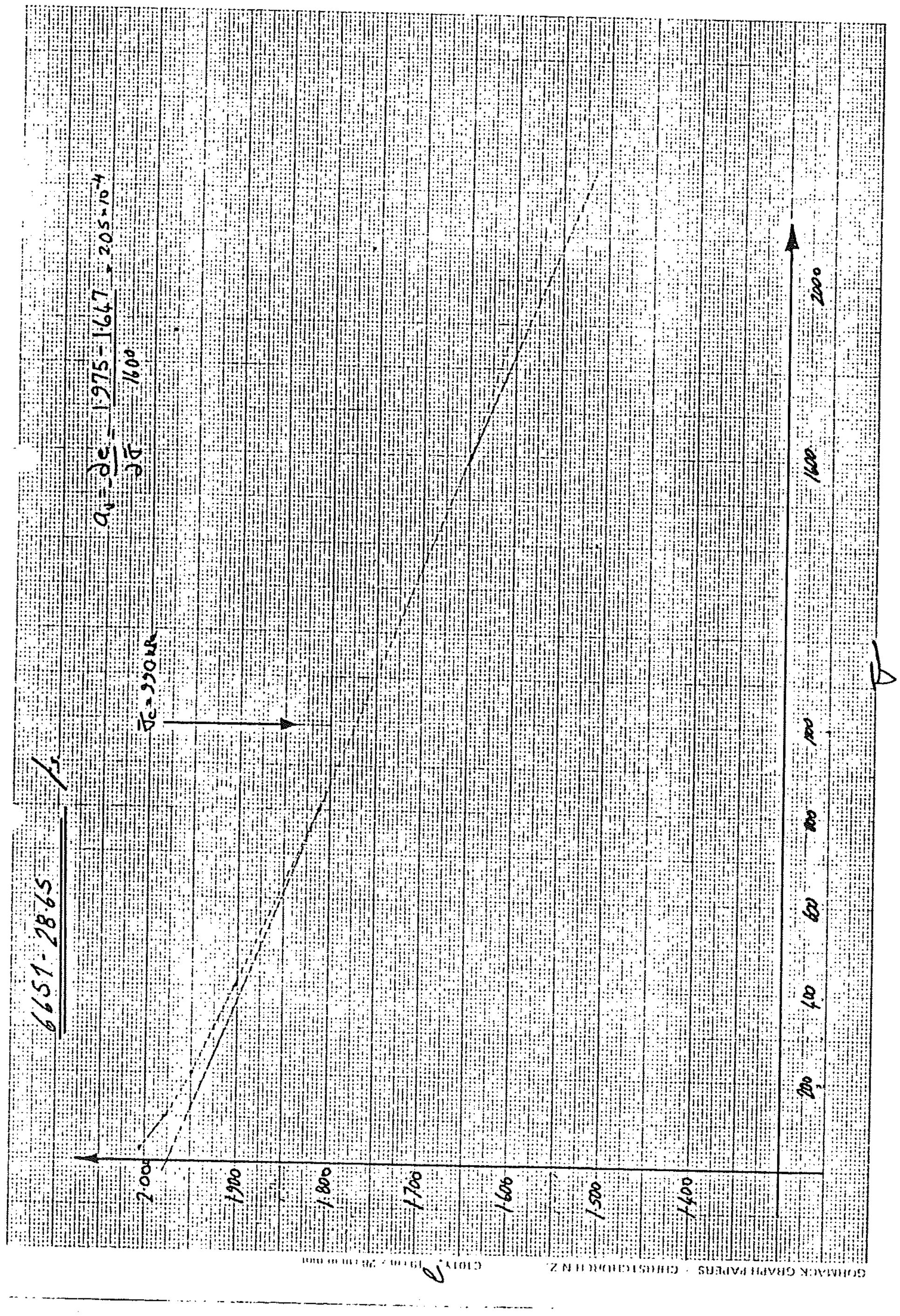
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.45 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19.423	H_f 15.813
Mass of ring + watch glass + wet specimen	g	M_3 256.183	M_4 248.015
Mass of ring + watch glass + dry specimen M_5	g		204.562
Mass of ring M_1	g	92.295	92.295
Mass of watch glass M_2	g	37.912	39.349
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		71.933
Mass of water	g	$M_3 - M_5$ 54.543	$M_4 - M_5$ 44.438
Water content w	%	w_i 75.8	w_f 61.8
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.810	ρ_{df} 0.995
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	6.420	6.420
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2.026	e_f 1.463
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 91.7	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.098	19.325			2.010
50		0.079	19.246			1.998
100		0.127	19.119			1.978
200		0.180	18.939			1.950
400		0.289	18.650			1.905
800		0.536	18.114			1.821
1600		1.121	16.993			1.647
3200		1.602	15.391			1.397
1600		- 0.028	15.419			1.402
800		- 0.041	15.460			1.408
400		- 0.047	15.507			1.415
100		- 0.096	15.603			1.430
25		- 0.079	15.682			1.443
0		- 0.131	15.813			1.463

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.




6651 · 28·65
$a_v = \frac{de}{d\sigma} = \frac{1.975 - 1.647}{1600} = 205 \times 10^{-4}$
$\sigma_c = 990$ kPa
2.000
1.900
1.800
1.700
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GORMACK GRAPH PAPERS - CHRISTCHURCH N.Z.

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

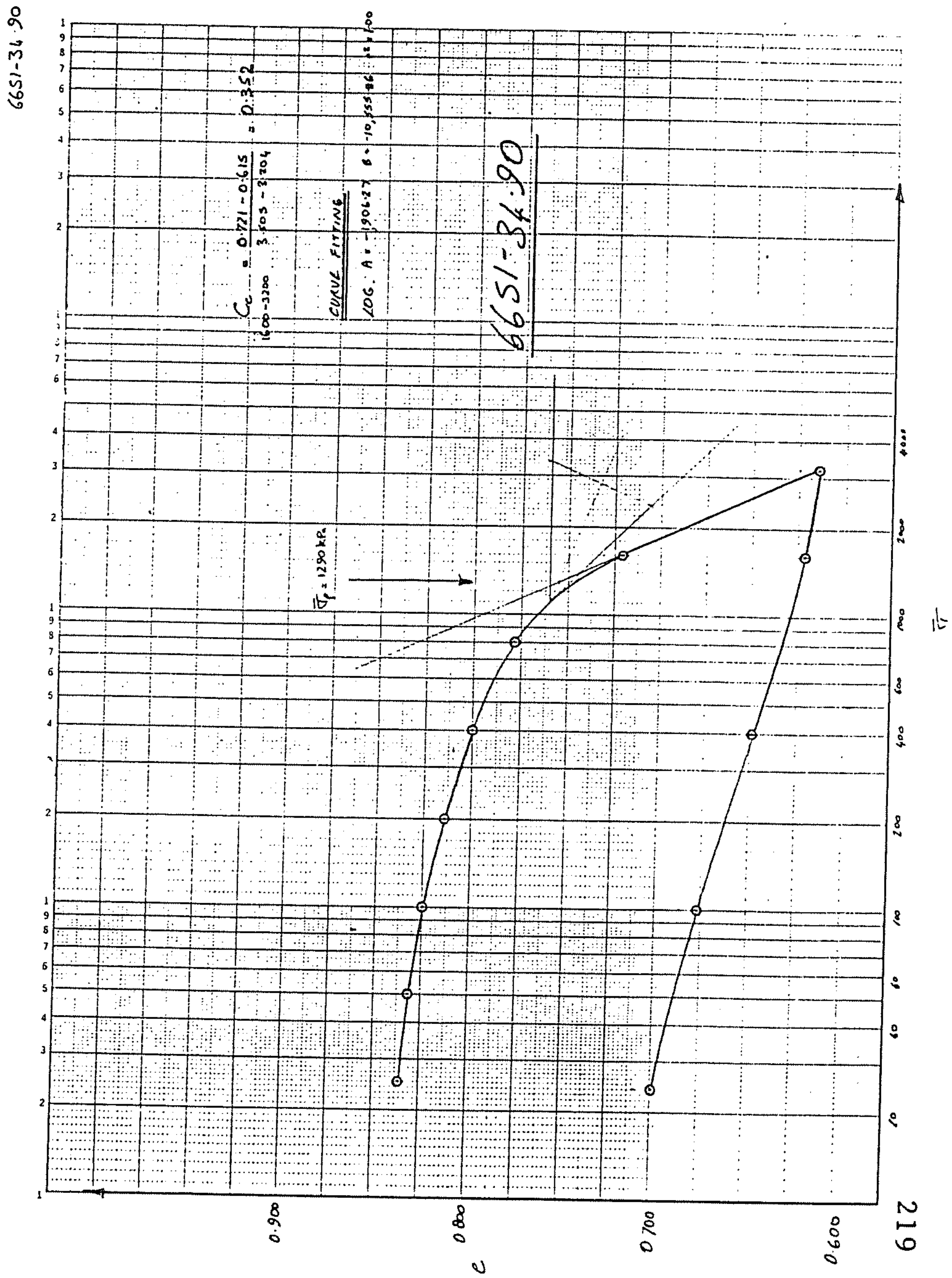
Job: NZED HOSTEL SUBSIDENCE — Sample No(s): 6651-34.90m
Sampling date: 8.1.85 — Tested by: P. KELSEY
Sampling location: GH6651 — Date: 17-24.6.85
Sampling depth: 34.90m — Checked by: P. KELSEY
Ground surface elevation: 21.73m — Date: 19.9.85
Water-table elevation: 12.70m
Test details:*

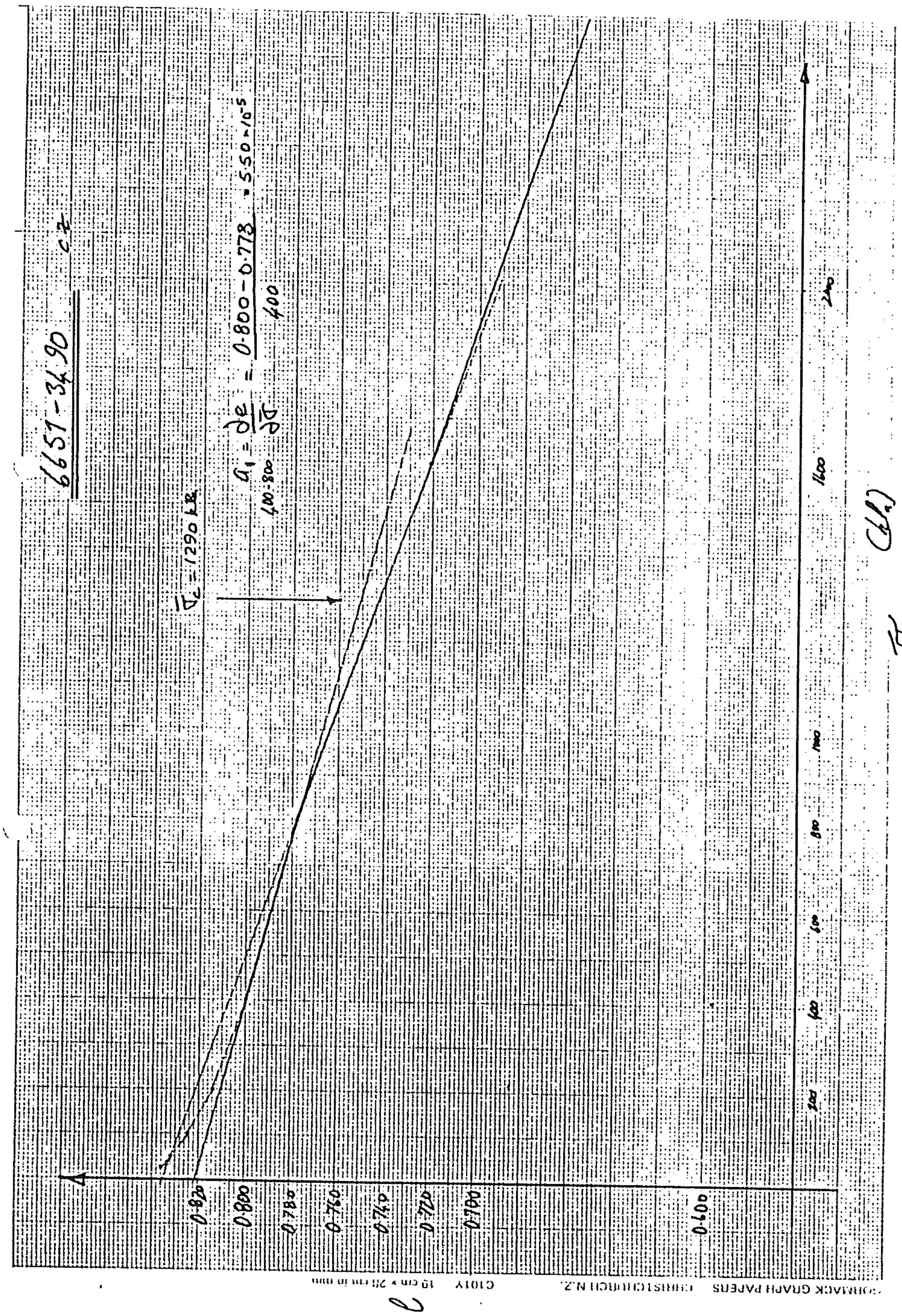
Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 24 hours/~~minutes~~
Specimen No.: 5
Cell No.: 5 — Diameter of ring (D) 76.12 mm
Machine No.: 5 — Height of ring 19.16 mm
Ring No.: 11 NEW 55 — Area of ring (A) = $\frac{\pi D^2}{4}$ 4550.80 mm²
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.62 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19.040	H_f 17.726
Mass of ring + watch glass + wet specimen	g	M_3 294.184	M_4 289.601
Mass of ring + watch glass + dry specimen M_5	g		253.930
Mass of ring M_1	g	91.259	91.259
Mass of watch glass M_2	g	40.263	39.450
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		123.221
Mass of water	g	$M_3 - M_5$ 39.441	$M_4 - M_5$ 35.671
Water content w	%	w_i 32.0	w_f 28.9
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 1.422	ρ_{df} 1.528
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	10.335	10.335
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 0.842	e_f 0.715
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 99.6	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.062	18.978			0.836
50		0.041	18.937			0.832
100		0.071	18.866			0.825
200		0.114	18.752			0.814
400		0.149	18.603			0.800
800		0.226	18.377			0.778
1600		0.587	17.790			0.721
3200		1.096	16.694			0.615
1600		-0.072	16.766			0.622
400		-0.274	17.040			0.649
100		-0.296	17.336			0.677
25		-0.225	17.561			0.699
0		-0.165	17.726			0.715

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.




6651-3490
$\bar{\sigma}_c = 1290$ kPa
$a_{1\,(400:800)} = \frac{\partial e}{\partial \sigma} = \frac{0.800-0.778}{400} = 5.50\times10^{-5}$
0.820
0.800
0.780
0.760
0.740
0.720
0.700
0.600
200
400
600
800
1000
1600
2400
σ (kPa)
e
CORMACK GRAPH PAPERS CHRISTCHURCH N.Z.

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED: HOSTEL SUBSIDENCE
Sampling date: 8.1.85
Sampling location: BH 6651
Sampling depth: 40.10 m.
Ground surface elevation:
Water-table elevation:

Sample No(s): 6651-40-10 Horiz.
Tested by: P. Kelsey
Date: 27.6.85 – 7.7.85
Checked by: P Kelsey.
Date: 13.9.85.

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.:

Cell No.: 5 Diameter of ring (D) 76.20 mm

Machine No.: 5 Height of ring 19.34 mm

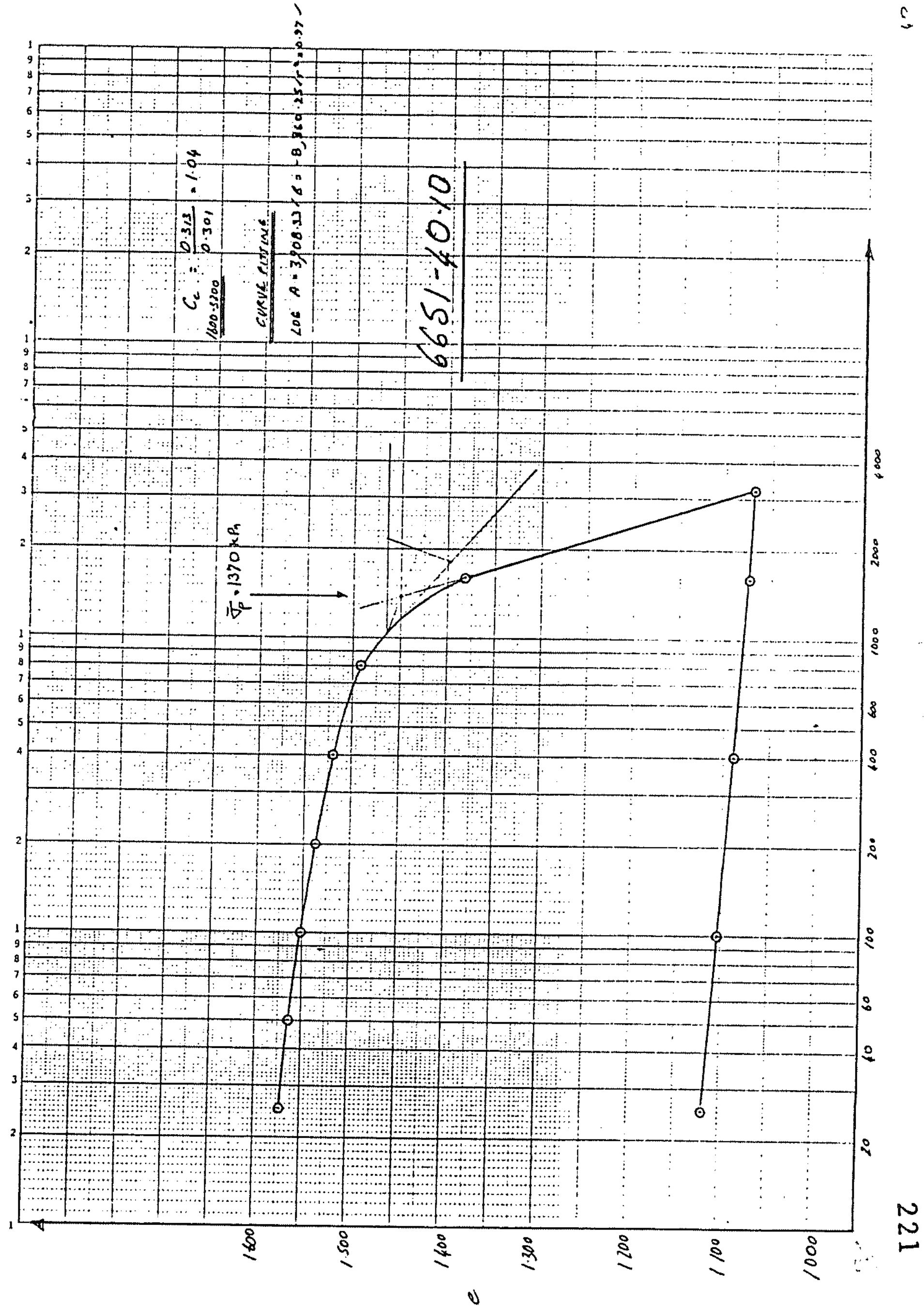
Ring No.: 1 N.SS Area of ring (A) = $\frac{\pi D^2}{4}$ 4560.37 mm²

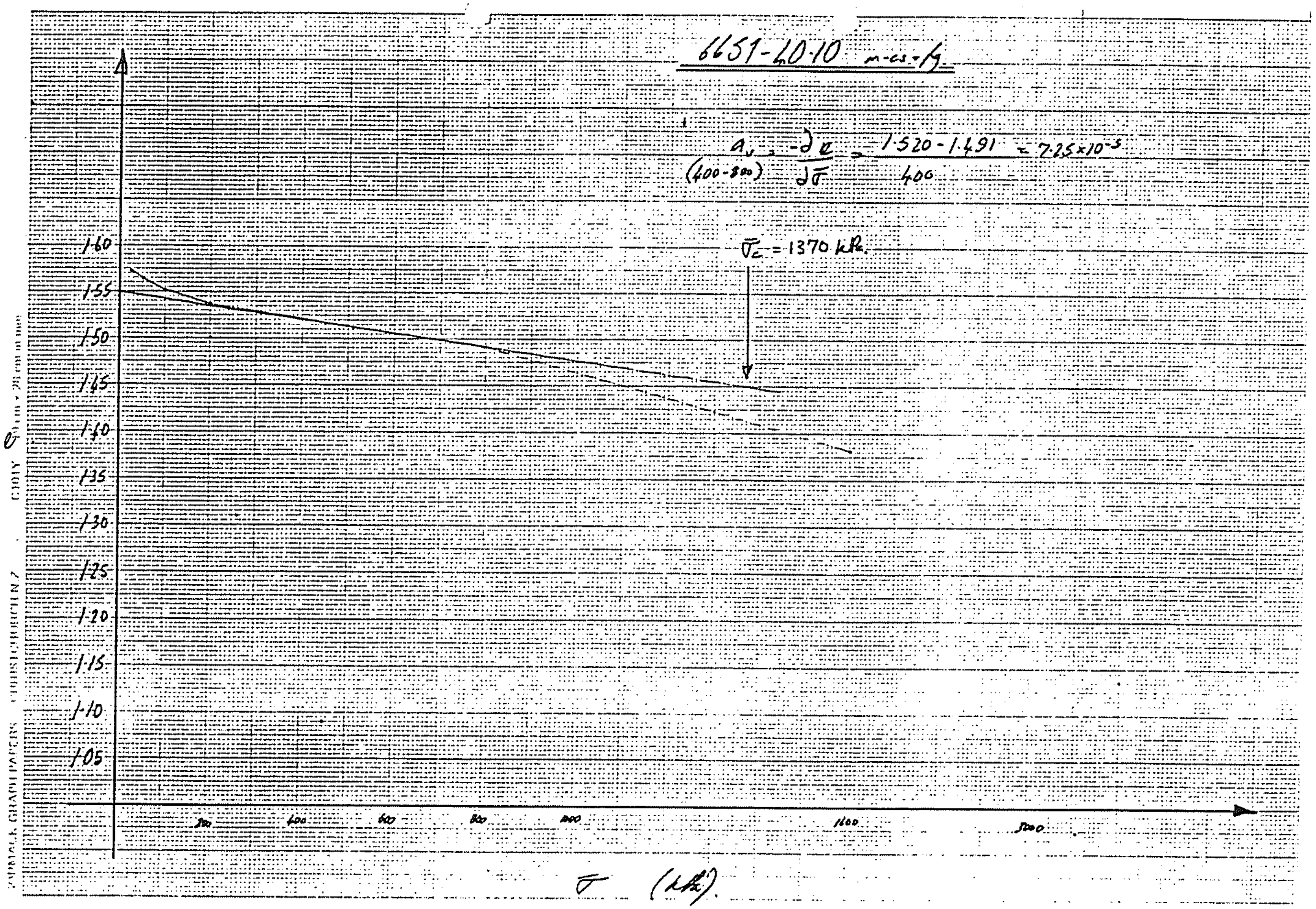
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.52 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_I 19.143	H_f 15.853
Mass of ring + watch glass + wet specimen	g	M_3 246.595	M_4 257.573
Mass of ring + watch glass + dry specimen M_5	g		214.613
Mass of ring M_1	g	90.376	90.376
Mass of watch glass M_2	g	39.173	38.297
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		84.955
Mass of water	g	M_3-M_5 52.?82	M_4-M_5 42.960
Water content w	%	w_I 61.3	w_f 50.6
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{dI} 0.973	ρ_{df} 1.175
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	7.392	7.392
Voids ratio $e = \frac{H - H_s}{H_s}$		e_I 1.590	e_f 1.144
Degree of saturation $S = \frac{\rho_s w}{e}$		S_I 97.2	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_I - \Delta H)$	% change thickness $\frac{H_I - H}{H_I}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.121	19.022			1.573
50		0.070	18.952			1.564
100		0.092	18.860			1.551
200		0.106	18.754			1.537
400		0.127	18.627			1.520
800		0.210	18.417			1.491
1600		0.805	17.612			1.382
3200		2.315	15.29?			1.019
1600		–0.034	15.331			1.074
400		–0.112	15.443			1.089
100		–0.110	15.553			1.104
25		–0.110	15.663			1.119
0		–0.190	15.853			1.144

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.




6651-40·10 m-cs-Yz
a_v (400-800) = $-\frac{\partial \varepsilon}{\partial T}$ = $\frac{1.520-1.491}{400}$ = 7.25×10^{-5}
T_c = 1370 kR.
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
200
400
600
800
1000
1600
2000
T (kR)

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED HOSTEL SUBSIDENCE	Sample No(s): 6651-43.70m horizontal
Sampling date: 8.1.86	Tested by: P. KELSEY
Sampling location: BH 6651	Date: 27.6.85 - 7.7.85
Sampling depth: 43.70m	Checked by: P. KELSEY
Ground surface elevation: 21.73m	Date: 18.9.85
Water-table elevation: 12.70m	

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.:

Cell No.: 6 — Diameter of ring (D) 76.02 mm

Machine No.: 6 — Height of ring 19.14 mm

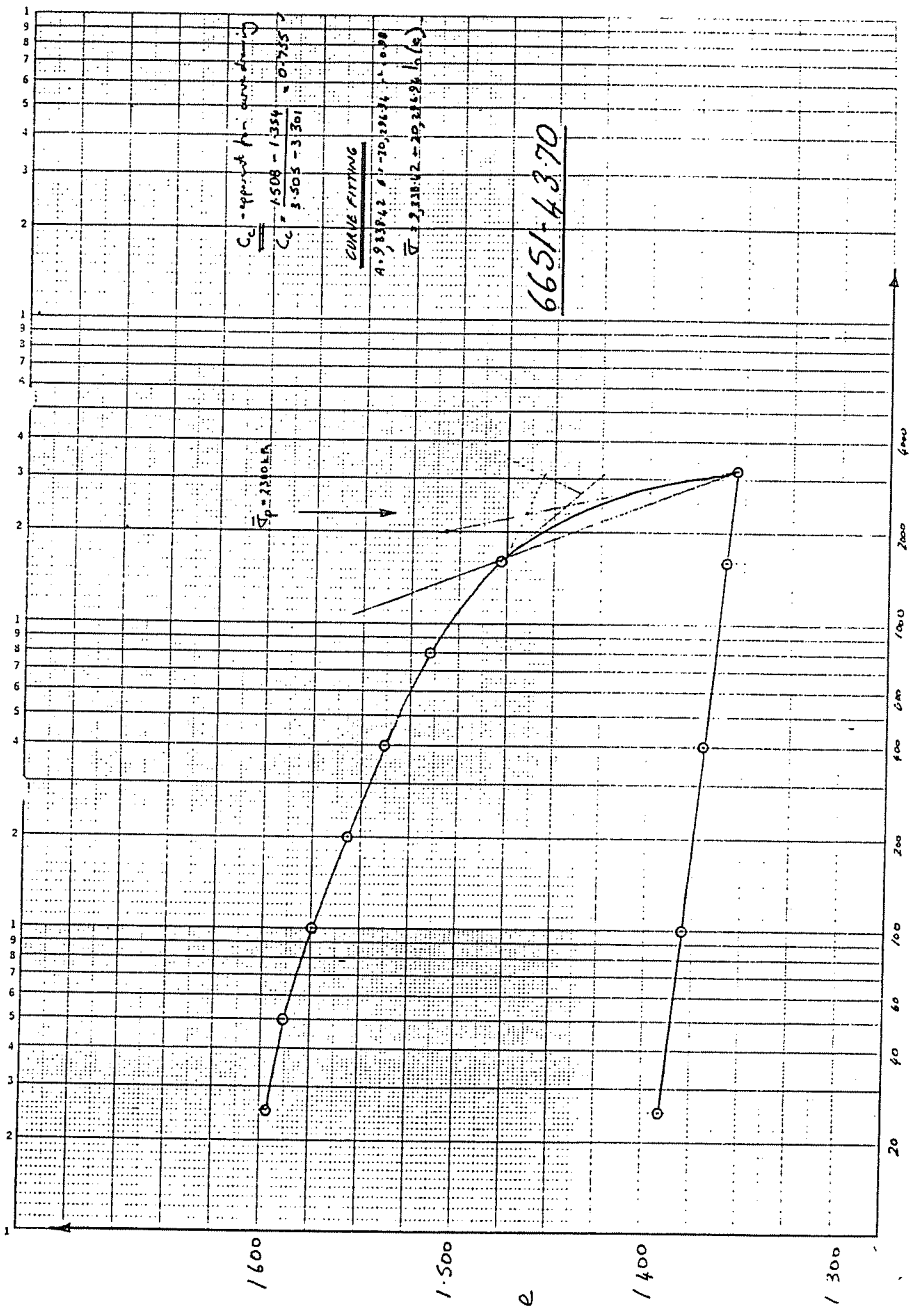
Ring No.: 6 OLD 55 — Area of ring $(A) = \frac{\pi D^2}{4}$ 4538.85 mm²

Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.39 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19.047	H_f 17.588
Mass of ring + watch glass + wet specimen	g	M_3 264.160	M_4 267.712
Mass of ring + watch glass + dry specimen M_5	g		215.550
Mass of ring M_1	g	94.563	94.563
Mass of watch glass M_2	g	37.929	40.647
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		79.355
Mass of water	g	$M_3 - M_5$ 52.313	$M_4 - M_5$ 52.162
Water content w	%	w_i 65.9	w_f 65.7
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.918	ρ_{df} 0.994
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	7.315	7.315
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 1.604	e_f 1.404
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 98.2	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.052	18.995			1.597
50		0.061	18.934			1.588
100		0.106	18.828			1.574
200		0.120	18.708			1.557
400		0.140	18.568			1.538
800		0.173	18.395			1.515
1600		0.272	18.123			1.478
3200		0.906	17.217			1.354
1600		-0.036	17.253			1.359
400		-0.082	17.335			1.370
100		-0.078	17.413			1.380
25		-0.079	17.492			1.391
0		-0.093	17.588			1.404

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



NZS 4402
Part 2P : 1981

FORM 21
DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

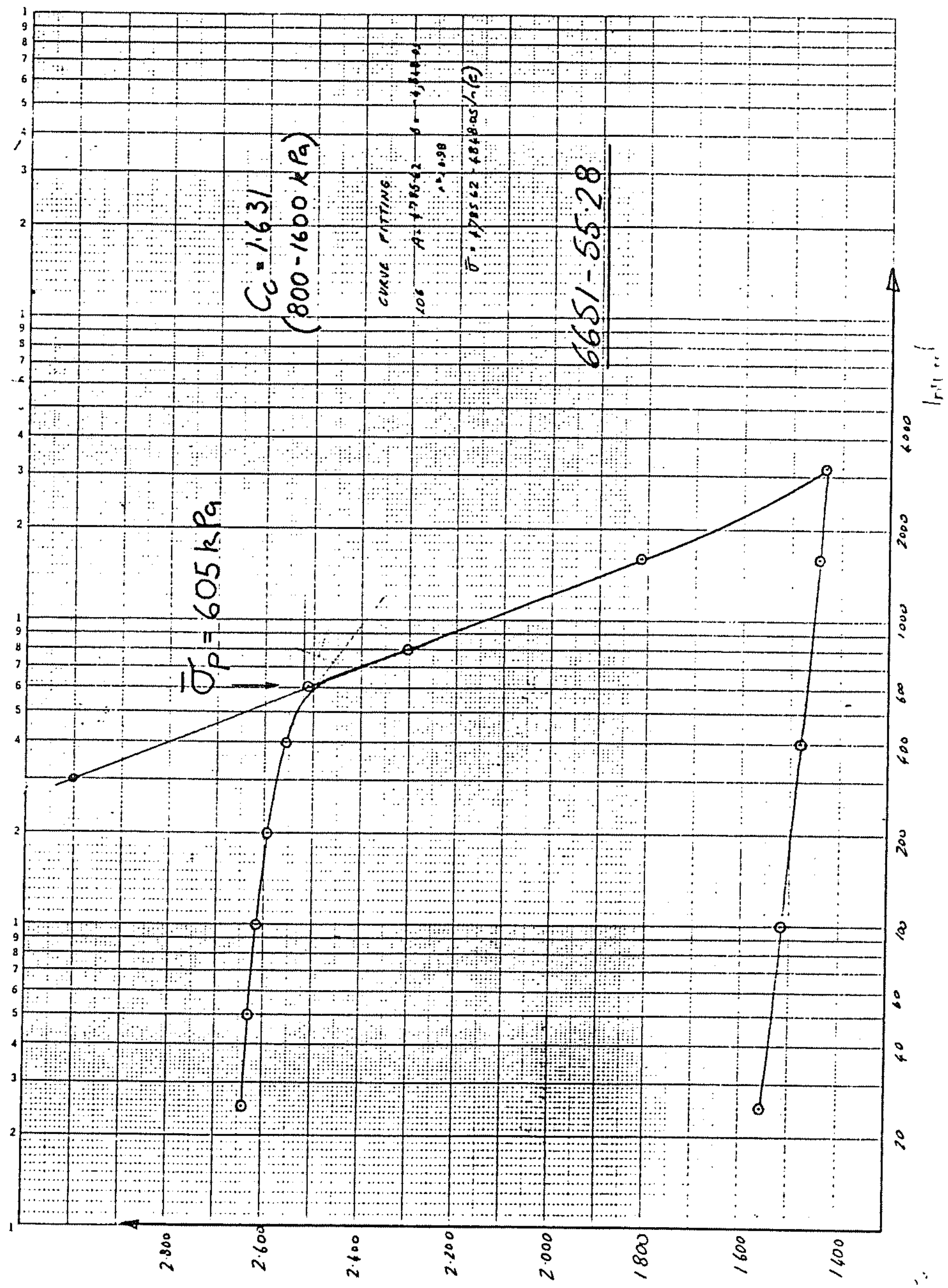
Job: NZFS HOSTEL SUBSIDENCE — Sample No(s): 6651-55·28
Sampling date: 8·1·86 — Tested by: P. Kelsey
Sampling location: BH6651 — Date: 8·6·85 – 16·6·85
Sampling depth: 55·28 m — Checked by: P. Kelsey
Ground surface elevation: — Date: 13·7·85
Water-table elevation:
Test details:*

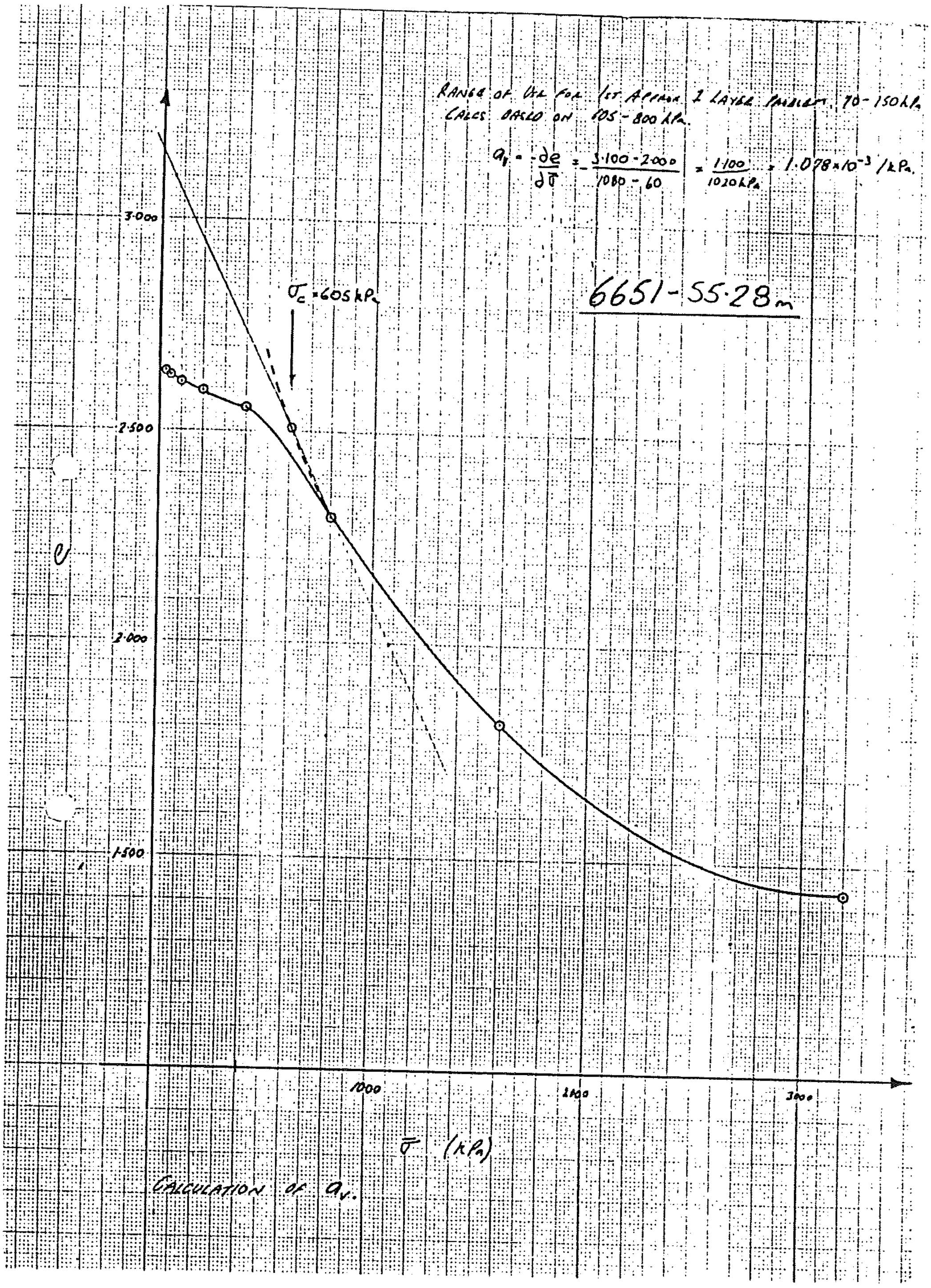
Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 24 hours/~~minutes~~
Specimen No.:
Cell No.: 4 — Diameter of ring (D) 76·19 mm
Machine No.: 4 — Height of ring 19·62 mm
Ring No.: 5 NEW — Area of ring (A) = $\frac{\pi D^2}{4}$ 4559·17 mm²
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2·69 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19·18	H_f 13·73
Mass of ring + watch glass + wet specimen	g	M_3 253·788	M_4 232·125
Mass of ring + watch glass + dry specimen M_5	g		190·944
Mass of ring M_1	g	86·053	86·053
Mass of watch glass M_2	g	40·389	40·652
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g	64·24	64·24
Mass of water	g	$M_3 - M_5$ 63·11	$M_4 - M_5$ 41·18
Water content w	%	w_i 98	w_f 64
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0·74	ρ_{df} 1·03
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	5·238	5·238
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2·662	e_f 1·621
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 99	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0·106	19·074			2·641
50		0·060	19·014			2·630
100		0·078	18·936			2·615
200		0·105	18·831			2·595
400		0·196	18·635			2·558
800		1·335	17·300			2·303
1600		2·571	14·729			1·812
3200		1·973	12·756			1·435
1600		0·064	12·820			1·447
400		0·173	12·993			1·481
100		0·194	13·187			1·518
25		0·185	13·372			1·553
0		0·358	13·730			1·621

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.




RANGE OF USE FOR 1ST APPROX 2 LAYER PROBLEM 70-150 kPa
CALCS BASED ON 605-800 kPa.
$a_v = -\frac{\partial e}{\partial \bar{\sigma}} = -\frac{3.100-2.000}{1080-60} = \frac{1.100}{1020\,kPa} = 1.078 \times 10^{-3}\,/kPa.$
$\sigma_c = 605\,kPa$
6651-55.28m
3.000
2.500
2.000
1.500
e
1000
2000
3000
$\bar{\sigma}$ (kPa)
CALCULATION OF a_v.

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

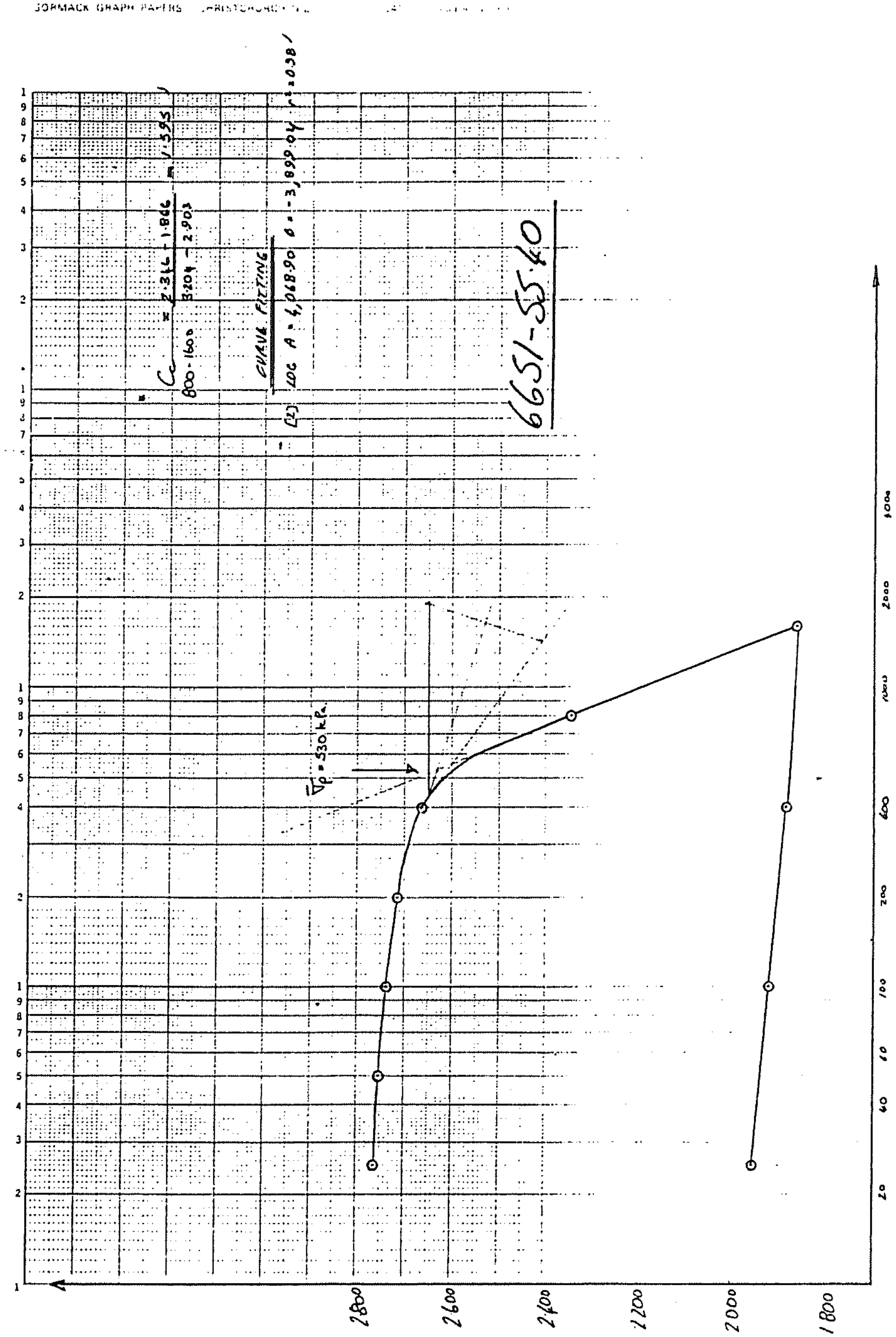
Job: N2LD HOSTC: SUBSIDENCE Sample No(s): 6651-55.40m (vert)
Sampling date: 9-1-85 Tested by: P KELSEY
Sampling location: BH6651 Date: 8-6-85-15-6-85
Sampling depth: 55.40m Checked by: P. KELSEY
Ground surface elevation: Date: 20-9-85
Water-table elevation:
Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 24 hours/~~minutes~~
Specimen No.:
Cell No.: 5 Diameter of ring (D) 76.12 mm
Machine No.: 5 Height of ring 19.25 mm
Ring No.: 3 NEW Area of ring (A) = $\frac{\pi D^2}{4}$ 4550.80 mm²
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.69 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19.187	H_f 15.291
Mass of ring + watch glass + wet specimen	g	M_3 253.442	M_4 238.816
Mass of ring + watch glass + dry specimen M_5	g		190.009
Mass of ring M_1	g	89.473	89.473
Mass of watch glass M_2	g	37.325	38.295
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		62.241
Mass of water	g	$M_3 - M_5$ 64.403	$M_4 - M_5$ 48.807
Water content w	%	w_i 103.5	w_f 78.4
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.713	ρ_{df} 0.894
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	5.084	5.084
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2.774	e_f 2.008
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 100	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.065	19.122			2.761
50		0.046	19.076			2.752
100		0.069	19.007			2.738
200		0.114	18.893			2.716
400		0.263	18.630			2.664
800		1.616	17.014			2.346
1600		2.443	14.571			1.866
400		-0.120	14.691			1.889
100		-0.162	14.853			1.921
25		-0.166	15.019			1.954
0		-0.272	15.291			2.008

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

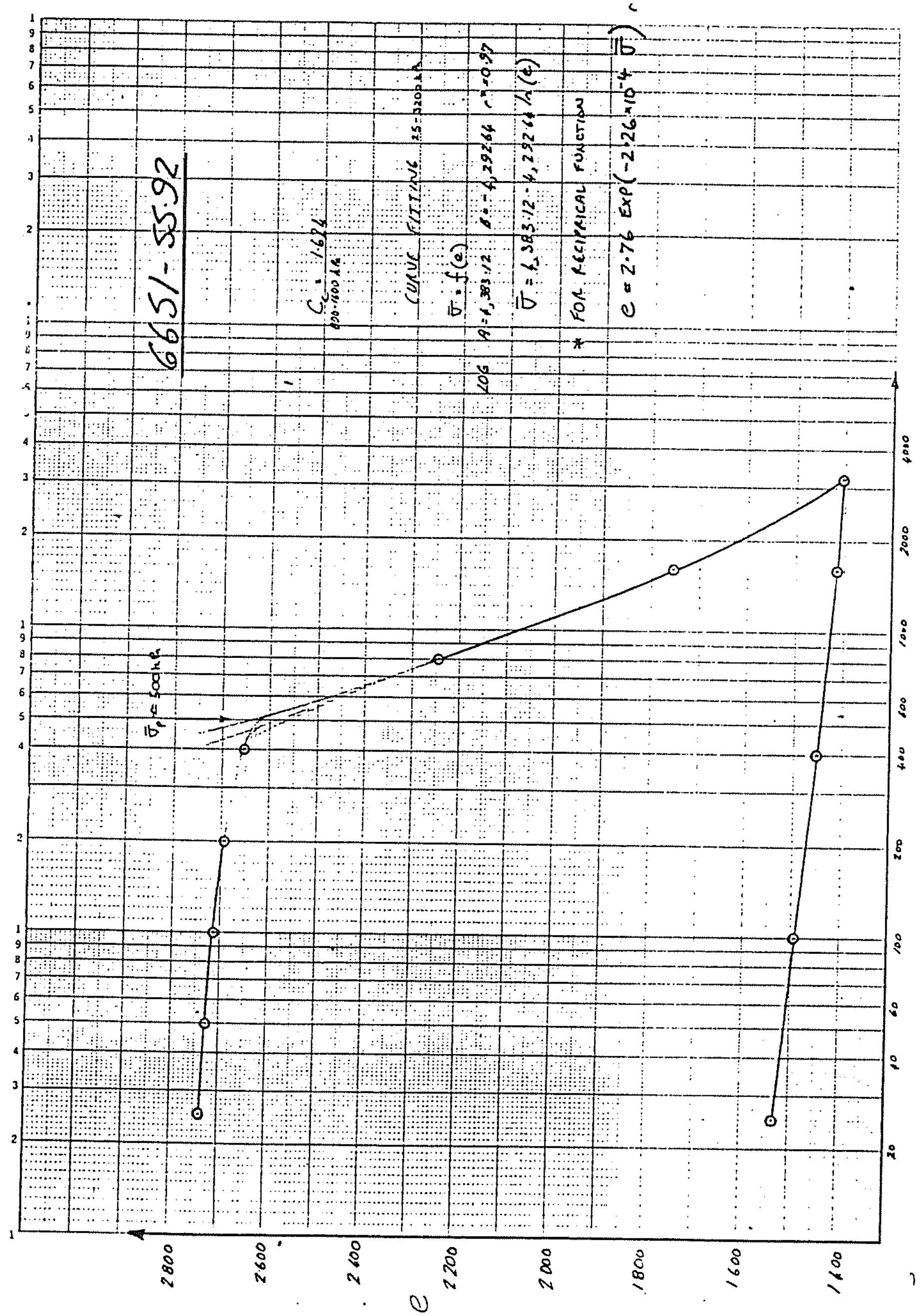
Job: NZED HOSTEL SUBSIDENCE — Sample No(s): 6651-55.92
Sampling date: 3.1.85 — Tested by: P. KELSEY
Sampling location: 8H6651 — Date: 29.8.85 - 8.9.85
Sampling depth: 55.92m — Checked by: P. KELSEY
Ground surface elevation: — Date: 13.9.85
Water-table elevation:
Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 24 hours/~~minutes~~
Specimen No.: 6651-55.92A
Cell No.: 3 — Diameter of ring (D) 76.08 mm
Machine No.: 3 — Height of ring 17.83 mm
Ring No.: 13NSS — Area of ring (A) = $\frac{\pi D^2}{4}$ 4546 mm²
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.69 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 17.83	H_f 12.283
Mass of ring + watch glass + wet specimen	g	M_3 239.150	M_4 217.855
Mass of ring + watch glass + dry specimen M_5	g		179.357
Mass of ring M_1	g		83.502
Mass of watch glass M_2	g	38.618	37.736
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		58.119
Mass of water	g	$M_3 - M_5$ 58.911	$M_4 - M_5$ 38.498
Water content w	%	w_i 101.4	w_f 66.2
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.717	ρ_{df} 1.041
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	4.753	4.753
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 2.751	e_f 1.584
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 99.2	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.060	17.770			2.739
50		0.050	17.720			2.728
100		0.075	17.645			2.712
200		0.104	17.541			2.691
400		0.169	17.372			2.655
800		1.960	15.412			2.243
1600		2.323	13.089			1.754
3200		1.669	11.420			1.403
1600		-0.065	11.485			1.416
400		-0.166	11.651			1.451
100		-0.190	11.841			1.491
25		-0.187	12.028			1.531
0		-0.255	12.283			1.584

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED HOSTEL SUBSIDENCE
Sample No(s): 6651 - 58.89
Sampling date: 8.1.85
Tested by: P. Kelsey
Sampling location: BH 6651
Date: 8.6.85 – 15.6.85
Sampling depth: 58.89 m
Checked by: P Kelsey
Ground surface elevation:
Date: 13.7.85
Water-table elevation:

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.: 6651 - 58.89

Cell No.: 6 Diameter of ring (D) 76.14 mm

Machine No.: 6 Height of ring 19.05 mm

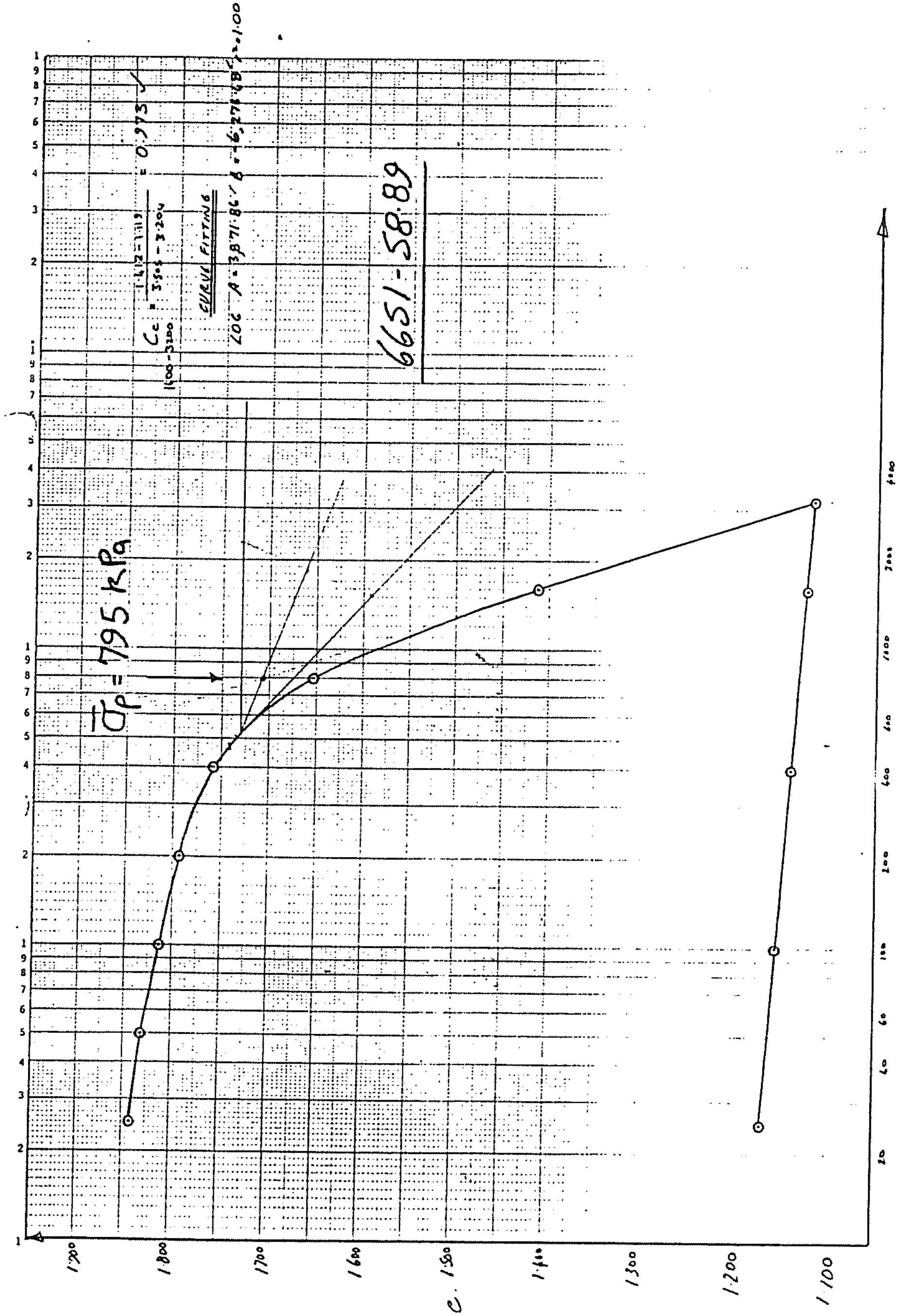
Ring No.: 4 NEW SS Area of ring $(A) = \frac{\pi D^2}{4}$ 4553.19 mm²

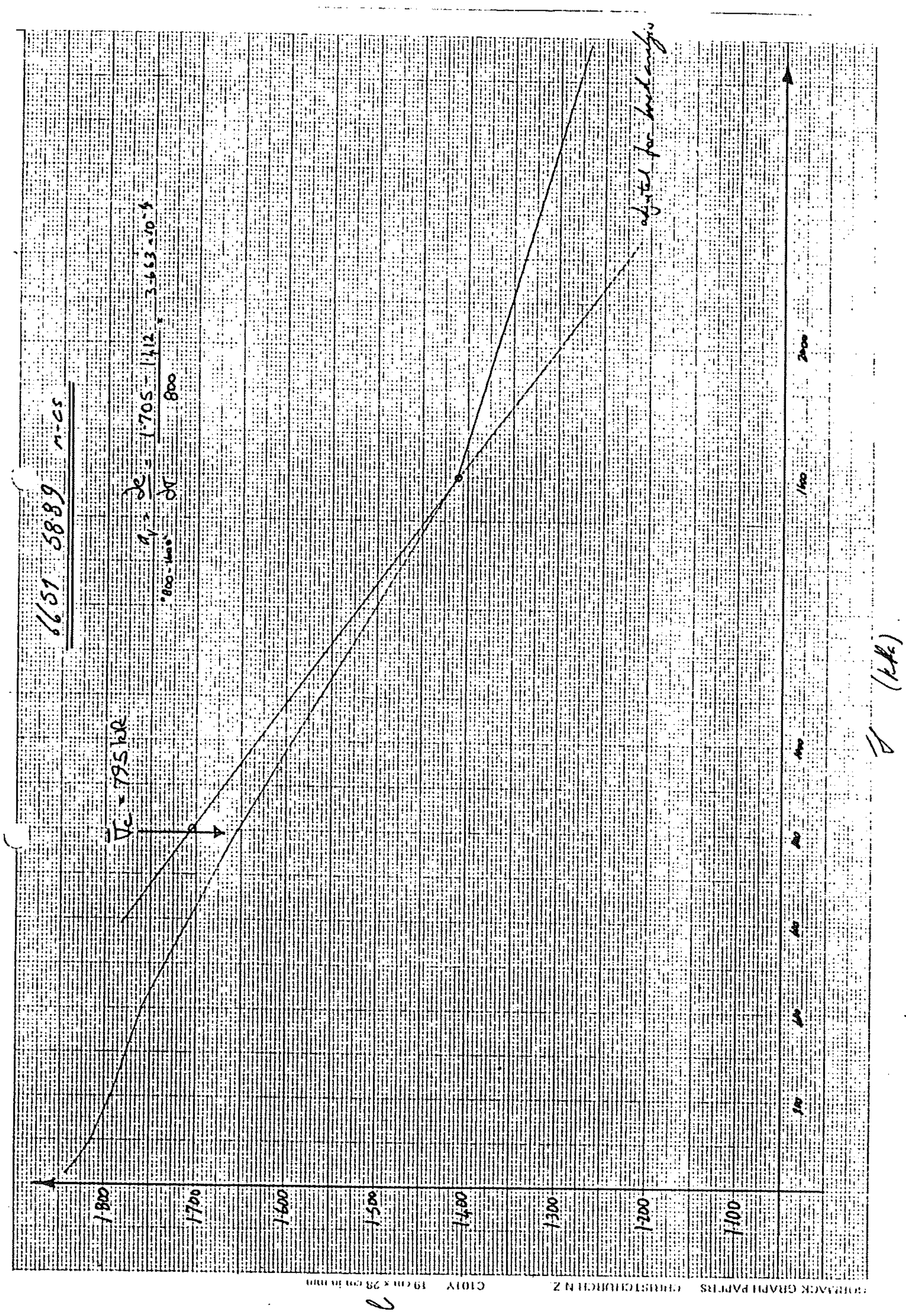
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.55 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 17.010	H_f 14.67
Mass of ring + watch glass + wet specimen	g	M_3 258.126	M_4 240.600
Mass of ring + watch glass + dry specimen M_5	g		203.001
Mass of ring M_1	g	87.487	87.487
Mass of watch glass M_2	g	38.752	38.158
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		77.356
Mass of water	g	M_3-M_5 54.531	M_4-M_5 37.599
Water content w	%	w_i 70.5	w_f 48.6
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.894	ρ_{df}
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	6.663	6.663
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 1.853	e_f
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 97	S_f

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.084	18.926			1.841
50		0.067	18.859			1.831
100		0.110	18.749			1.814
200		0.141	18.608			1.793
400		0.225	18.383			1.759
800		0.710	17.673			1.653
1600		1.606	16.067			1.412
3200		1.952	14.115			1.119
1600		−0.041	14.156			1.125
400		−0.102	14.258			1.140
100		−0.101	14.359			1.155
25		−0.088	14.447			1.168
0		−0.212	14.659			1.200

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.




1·800
1·700
1·600
1·500
1·400
1·300
1·200
1·100

NZS 4402
Part 2P : 1981

FORM 21
DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

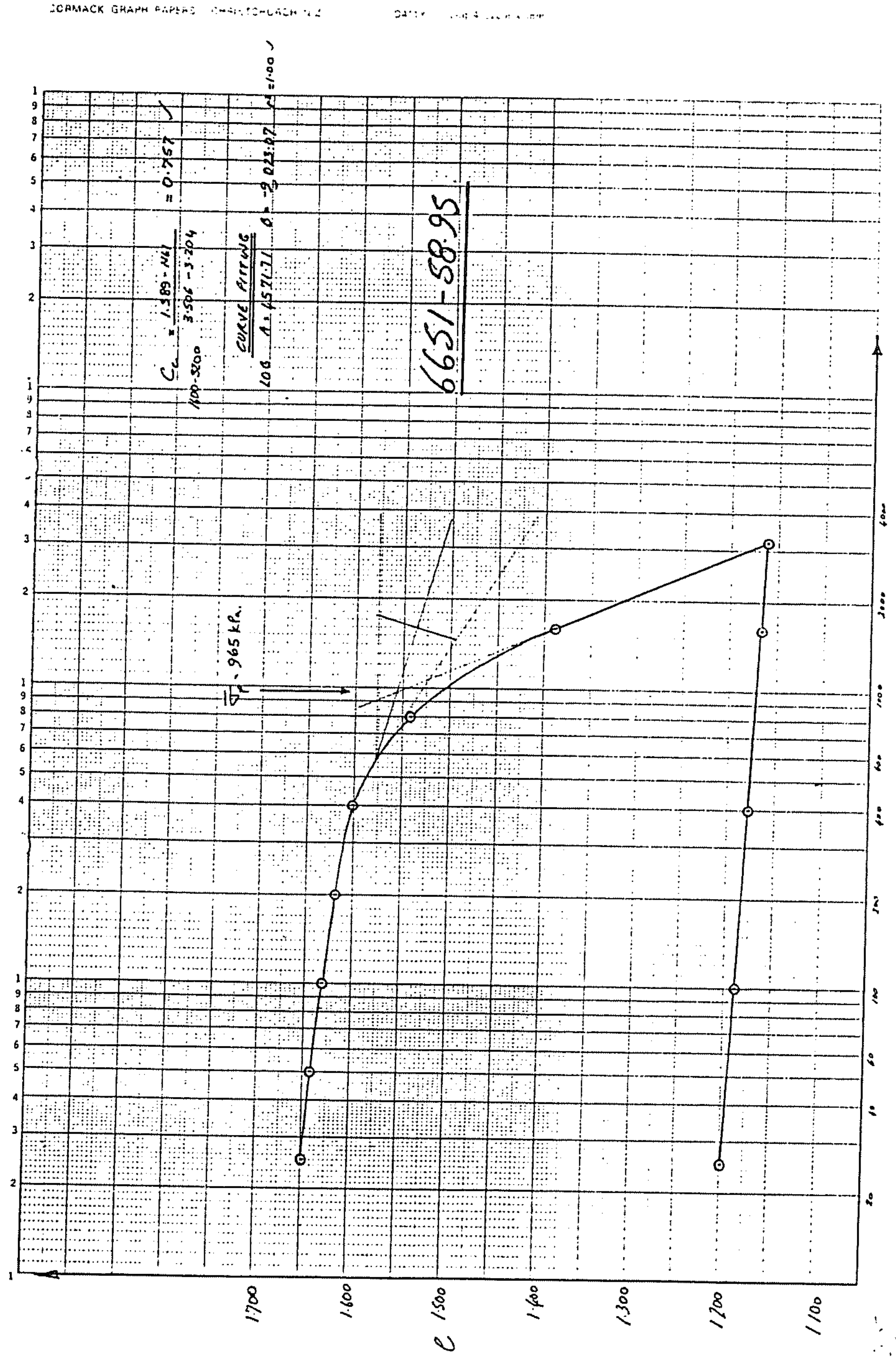
Job: NZED HOSTEL SUBSIDENCE — Sample No(s): 6651 – 58.95
Sampling date: 8.1.85 — Tested by: P. KELSEY
Sampling location: BH6651 — Date: 10.6.85 – 17.6.85
Sampling depth: 58.95 m — Checked by: P. Kelsey
Ground surface elevation: — Date: 26.9.85
Water-table elevation:
Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 24 hours/~~minutes~~
Specimen No.:
Cell No.: 3 — Diameter of ring (D) 76.20 mm
Machine No.: 3 — Height of ring 19.25 mm
Ring No.: 2 NEW RING — Area of ring (A) = $\frac{\pi D^2}{4}$ 4560.37 mm²
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.55 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19.220	H_f 15.958
Mass of ring + watch glass + wet specimen	g	M_3 263.983	M_4 252.161
Mass of ring + watch glass + dry specimen M_5	g		210.845
Mass of ring M_1	g	88.698	88.698
Mass of watch glass M_2	g	38.369	37.980
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		84.167
Mass of water	g	$M_3 - M_5$ 52.749	$M_4 - M_5$ 41.316
Water content w	%	w_i 62.7	w_f 49.1
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 0.960	ρ_{df} 1.157
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	7.238	7.238
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 1.656	e_f 1.205
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 96.5	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.056	19.164			1.648
50		0.051	19.113			1.641
100		0.069	19.044			1.631
200		0.097	18.947			1.618
400		0.125	18.822			1.601
800		0.426	18.396			1.542
1600		1.108	17.288			1.389
3200		1.646	15.642			1.161
1600		−0.032	15.674			1.166
400		−0.083	15.757			1.177
100		−0.083	15.840			1.189
25		−0.071	15.911			1.198
0		−0.047	15.958			1.205

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



NZS 4402
Part 2P : 1981

FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED-Hostel Subsidence	Sample No(s): 6651-60.95
Sampling date: 8.1.85	Tested by: P. Kelsey
Sampling location: BH6651	Date: 10.6.85 - 17.6.85
Sampling depth: 60.95 m	Checked by: P. Kelsey.
Ground surface elevation:	Date: 20.9.85

Water-table elevation:

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.:

Cell No.: 2 Diameter of ring (D) 76.13 mm

Machine No.: 2 Height of ring 18.410 mm

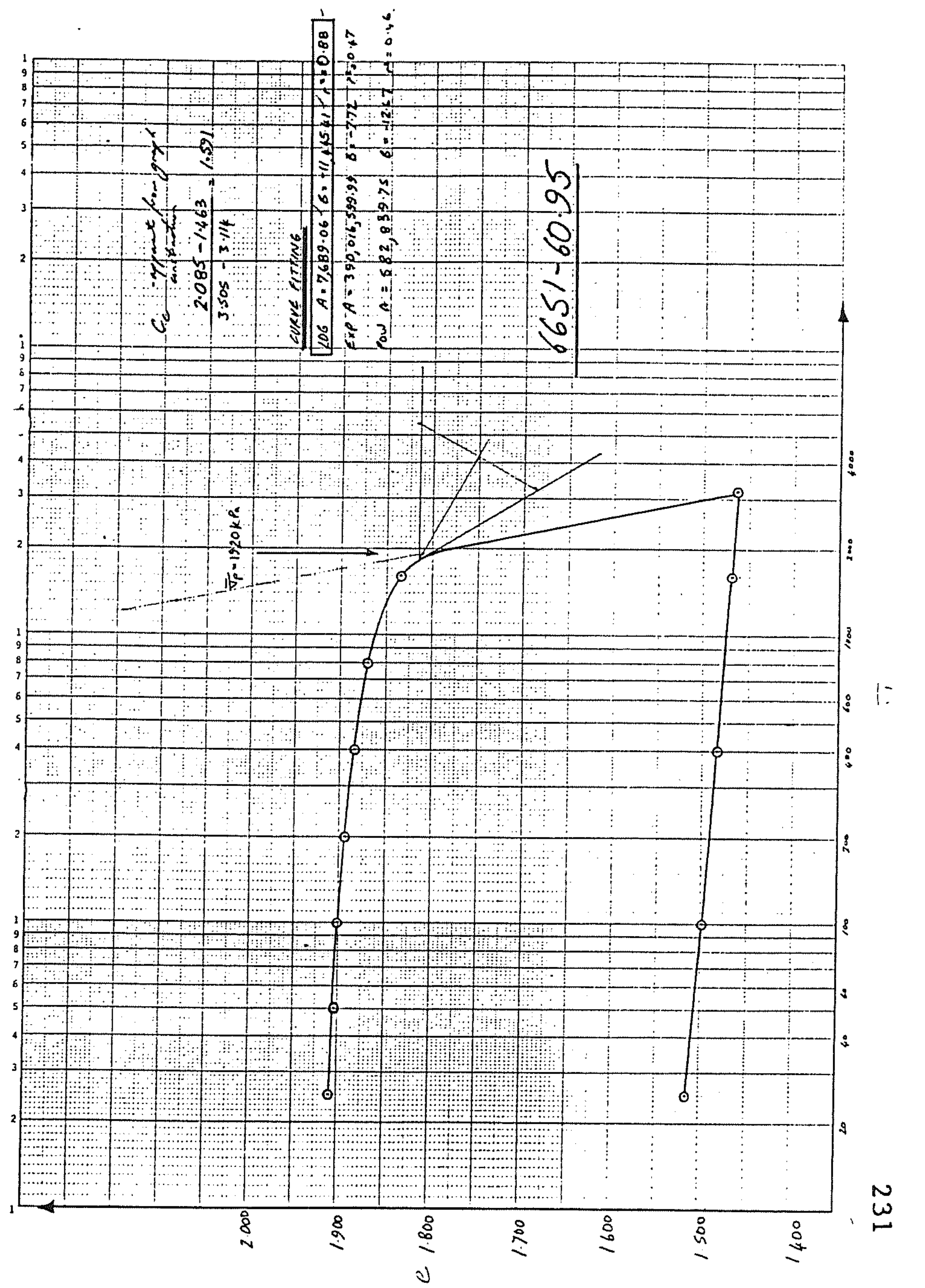
Ring No.: 9 NEW RING Area of ring $(A) = \frac{\pi D^2}{4}$ 4551.99 mm^2

Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.46 t/m^3

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 18.347	H_f 15.933
Mass of ring + watch glass + wet specimen	g	M_3 249.017	M_4 238.090
Mass of ring + watch glass + dry specimen M_5	g		192.931
Mass of ring M_1	g	83.724	83.724
Mass of watch glass M_2	g	40.392	38.623
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		70.584
Mass of water	g	$M_3 - M_5$ 54.317	$M_4 - M_5$ 45.159
Water content w	%	w_i 77.0	w_f 64.0
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m^3	ρ_{di} 0.845	ρ_{df} 0.973
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	6.303	6.303
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 1.911	e_f 1.528
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 99.1	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.022	18.325			1.907
50		0.018	18.307			1.904
100		0.021	18.286			1.901
200		0.045	18.241			1.894
400		0.061	18.180			1.884
800		0.089	18.091			1.870
1600		0.224	17.867			1.835
3200		2.344	15.523			1.463
1600		-0.028	15.551			1.467
400		-0.102	15.653			1.483
100		-0.099	15.752			1.499
25		-0.100	15.852			1.515
0		-0.081	15.933			1.528

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



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FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED Upstel Subsidence	Sample No(s): 6651 – 61.85
Sampling date: 8.1.85	Tested by: P. Kelsey
Sampling location: BH 6651	Date: 10.6.85 – 17.6.85
Sampling depth: 61.85m	Checked by: P Kelsey
Ground surface elevation:	Date: 20.°.85
Water-table elevation:	

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.:

Cell No.: 1 — Diameter of ring (D) 76.15 mm

Machine No.: 1 — Height of ring 18.31 mm

Ring No.: 8 NEW 55 — Area of ring (A) = $\frac{\pi D^2}{4}$ 4554.38 mm^2

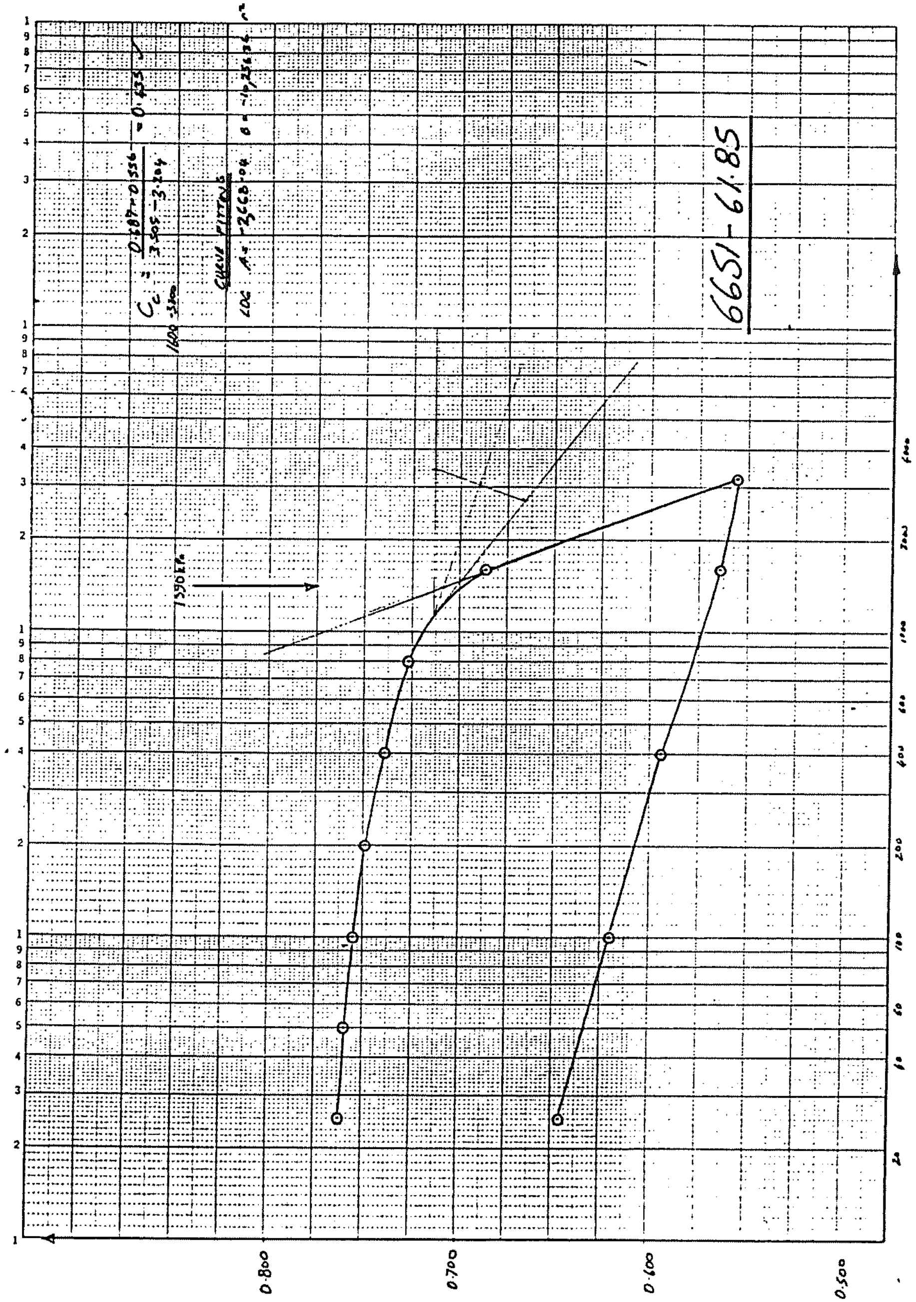
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.63 t/m^3

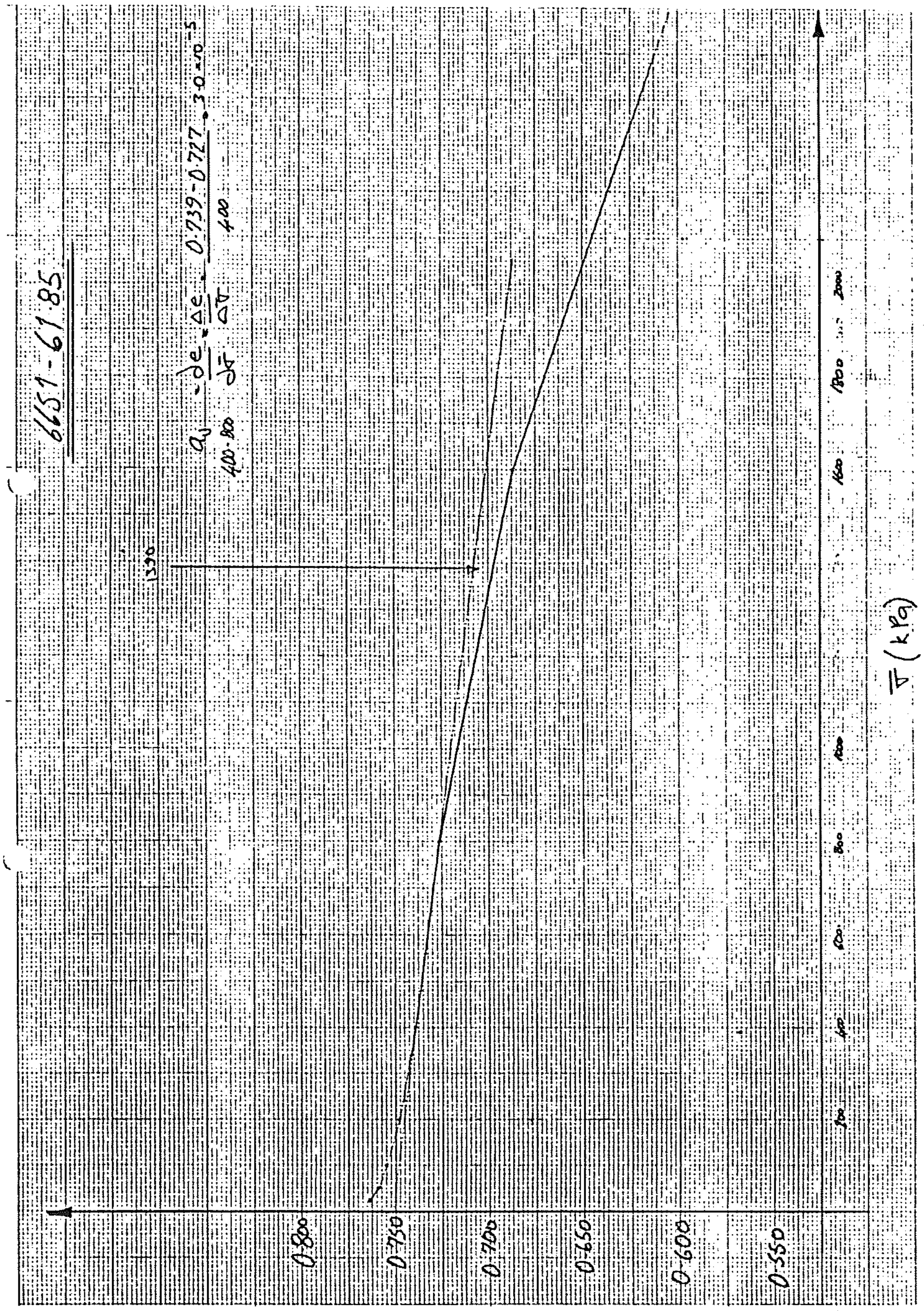
Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 18.333	H_f 17.211
Mass of ring + watch glass + wet specimen	g	M_3 283.711	M_4 279.622
Mass of ring + watch glass + dry specimen M_5	g		246.371
Mass of ring M_1	g	84.232	84.232
Mass of watch glass M_2	g	38.752	37.833
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		124.306
Mass of water	g	$M_3 - M_5$ 36.421	$M_4 - M_5$ 33.251
Water content w	%	w_i 29.3	w_f 26.7
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m^3	ρ_{di} 1.489	ρ_{df} 1.526
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	10.378	10.378
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 0.767	e_f 0.658
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 100	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H ($H_i - \Delta H$)	% change thickness $\frac{H_i - H}{H_i}$	Height of voids ($H - H_s$)	Voids ratio $\frac{H - H_s}{H_s}$
kPa		mm	mm	%	mm	
25		0.045	18.288			0.762
50		0.029	18.259			0.759
100		0.045	18.214			0.755
200		0.076	18.138			0.748
400		0.090	18.048			0.739
800		0.126	17.922			0.727
1600		0.416	17.506			0.687
3200		1.354	16.152			0.556
1600		−0.081	16.233			0.564
400		−0.309	16.542			0.594
100		−0.272	16.814			0.620
25		−0.270	17.084			0.646
0		−0.127	17.211			0.658

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.

CORMACK GRAPH PAPERS CHRISTCHURCH N Z — D411Y — Log 4 cycle x mm





6651-61.85
$a_v = -\frac{de}{d\bar{\sigma}} = \frac{\Delta e}{\Delta \bar{\sigma}} = \frac{0.739-0.727}{400} = 3.0\times10^{-5}$
400-800
1390
$\bar{\sigma}$ (kPa)
e
0.800
0.750
0.700
0.650
0.600
0.550
200
400
600
800
1000
1600
1800
2000

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FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED HOSTEL SUBSIDENCE
Sample No(s): 6651 – 66-30

Sampling date: 8·1·85
Tested by: P. Kelsey.

Sampling location: EH6651
Date: 17·6·85 – 24·6·85

Sampling depth: 66·30m
Checked by: P Kelsey

Ground surface elevation:
Date: 19.9.85.

Water-table elevation:

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.:

Cell No.: 6
Diameter of ring (D) 76·08 mm

Machine No.: 6
Height of ring 17·83 mm

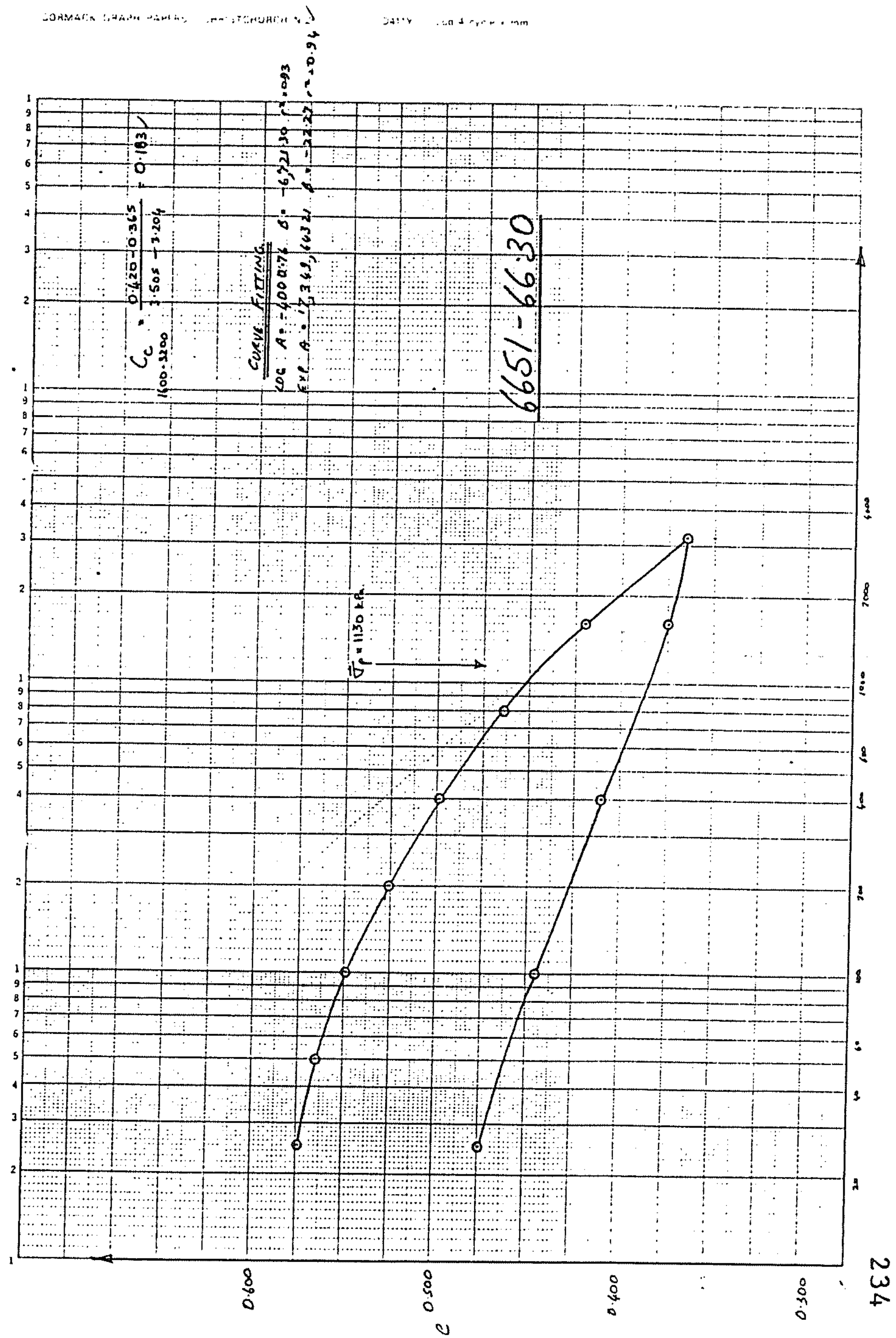
Ring No.: 13 new SS
Area of ring (A) = $\frac{\pi D^2}{4}$ 4546·02 mm^2

Solid density of soil particles measured/assumed (ρ_s) 2·62 t/m^3

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 17·700	H_f 16·812
Mass of ring + watch glass + wet specimen	g	M_3 287·938	M_4 284·539
Mass of ring + watch glass + dry specimen M_5	g		256·445
Mass of ring M_1	g	83·502	83·502
Mass of watch glass M_2	g	38·725	39·303
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		133·640
Mass of water	g	$M_3 - M_5$ 32·071	$M_4 - M_5$ 28·094
Water content w	%	w_i 24	w_f 21
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m^3	ρ_{di} 1·661	ρ_{df} 1·749
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	11·220	11·220
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 0·578	e_f 0·498
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 100	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0·037	17·663			0·574
50		0·103	17·560			0·565
100		0·189	17·371			0·548
200		0·250	17·121			0·526
400		0·314	16·807			0·498
800		0·377	16·430			0·464
1600		0·500	15·930			0·420
3200		0·619	15·311			0·365
1600		−0·119	15·430			0·375
400		−0·392	15·822			0·410
100		−0·387	16·209			0·445
25		−0·327	16·536			0·474
0		−0·276	16·812			0·498

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



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FORM 21
DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

Job: NZED HOSTEL SUBSIDENCE
Sample No(s): 6652 – 39.50
Sampling date: 21. 1. 85
Tested by: P. Kelsey, D Stewart
Sampling location: BH6652
Date: 31.5.85 – 7.6.85
Sampling depth: 39 50m
Checked by: P Kelsey
Ground surface elevation:
Date: 27.9.85.
Water-table elevation:

Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~

Loading cycle: 24 hours/~~minutes~~

Specimen No.:

Cell No.: 5 Diameter of ring (D) 76.20 mm

Machine No.: 5 Height of ring 19.34 mm

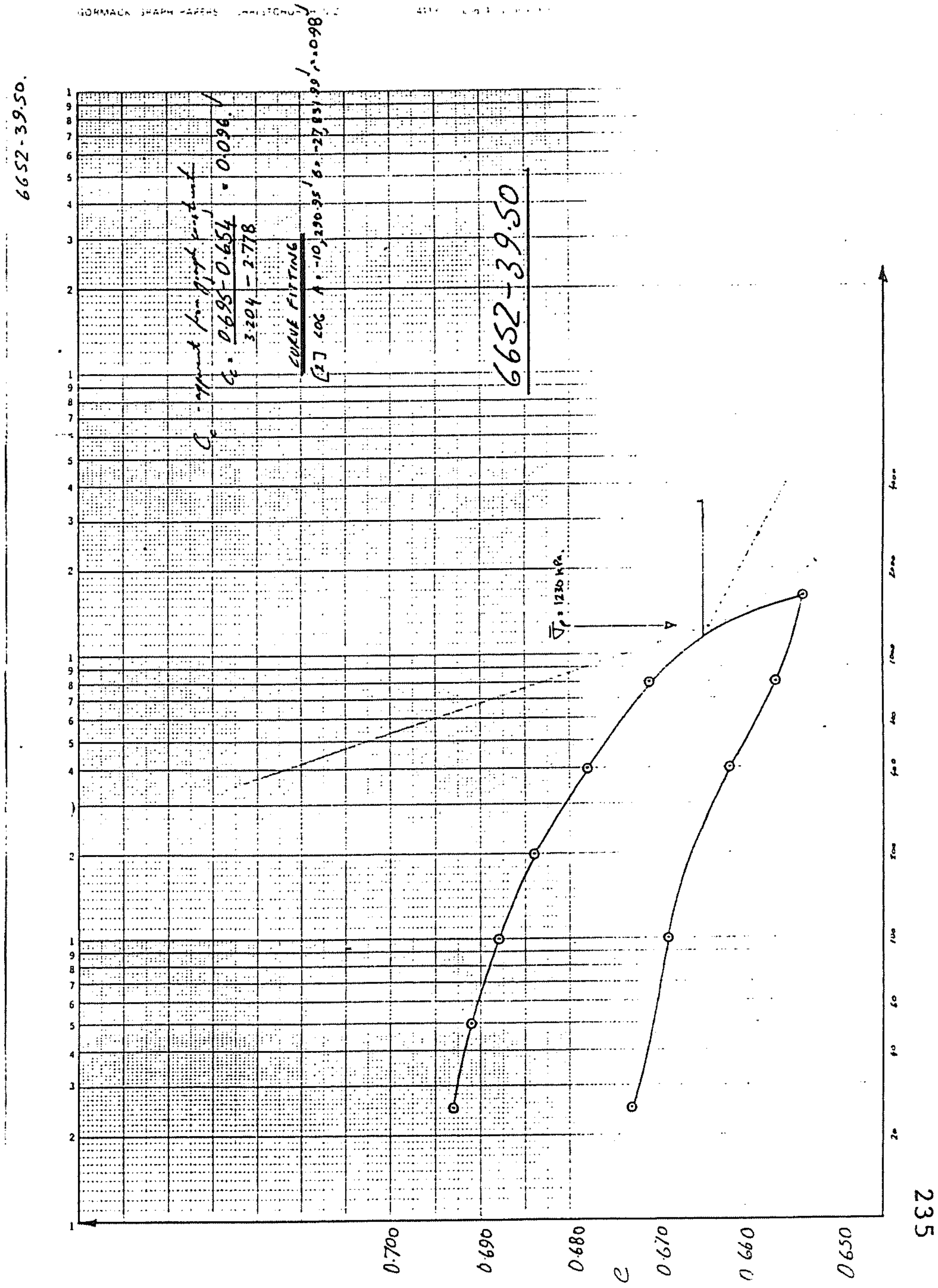
Ring No.: 1 (NEW SS) Area of ring $(A) = \frac{\pi D^2}{4}$ 4560.37 mm²

Solid density of soil particles measured/assumed (ρ_s) 2.63 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 19.560	H_f 19.443
Mass of ring + watch glass + wet specimen	g	M_3 304.185	M_4 304.554
Mass of ring + watch glass + dry specimen M_5	g		267.759
Mass of ring M_1	g	90.376	90.376
Mass of watch glass M_2	g	39.440	39.142
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		138.241
Mass of water	g	$M_3 - M_5$ 36.122	$M_4 - M_5$ 36.795
Water content w	%	w_i 26.1	w_f 26.6
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 1.550	ρ_{df} 1.559
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	11.526	11.526
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 0.697	e_f 0.687
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 98.5	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.047	19.513			0.693
50		0.020	19.493			0.691
100		0.035	19.458			0.688
200		0.050	19.408			0.684
400		0.062	19.346			0.678
800		[illegible]	19.255			0.671
1600		0.187	19.068			0.654
800		·0.036	19.104			0.657
400		-0.047	19.151			0.662
100		-0.081	19.232			0.669
25		-0.054	19.286			0.673
0			19.443			0.687

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



FORM 21

DETERMINATION OF THE ONE-DIMENSIONAL CONSOLIDATION PROPERTIES

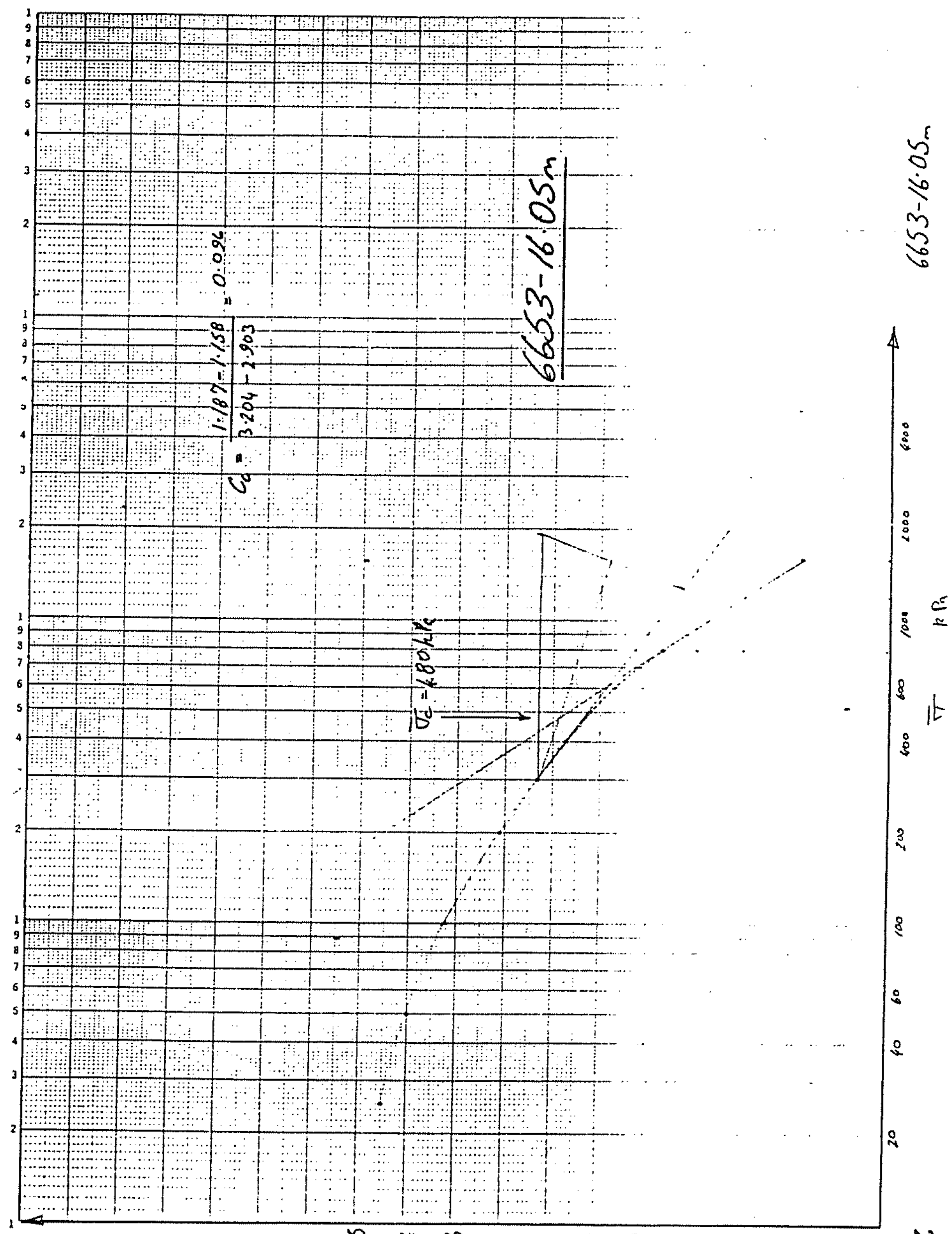
Job: NZED · HOTEL SUBSIDENCE — Sample No(s): 6653-16.05m
Sampling date: 17.1.85 — Tested by: P Kelsey.
Sampling location: BH6653 — Date: 22.5.86 – 31.5.86
Sampling depth: 16.05m — Checked by: P. Kelsey.
Ground surface elevation: — Date:
Water-table elevation:
Test details:*

Soil description: Undisturbed/~~remoulded/compacted/slurried/unknown~~
Loading cycle: 24 hours/~~minutes~~
Specimen No.:
Cell No.: 5 — Diameter of ring (D) 76.08 mm
Machine No.: 5 — Height of ring 17.83 mm
Ring No.: 13 NSS — Area of ring $(A) = \frac{\pi D^2}{4}$ 4546.02 mm²
Solid density of soil particles measured/~~assumed~~ (ρ_s) 2.38 t/m³

Stage:		Initial	Final
Measured thickness of specimen (H)	mm	H_i 17.860	H_f 17.256
Mass of ring + watch glass + wet specimen	g	M_3 252.536	M_4 252.436
Mass of ring + watch glass + dry specimen M_5	g		208.186
Mass of ring M_1	g	83.502	83.502
Mass of watch glass M_2	g	38.987	39.051
Mass of dry specimen $M_s = M_5 - M_1 - M_2$	g		85.633
Mass of water	g	$M_3 - M_5$ 44.414	$M_4 - M_5$ 44.250
Water content w	%	w_i 51.9	w_f 51.7
Dry density $\rho_d = \frac{M_s}{H \times A}$	t/m³	ρ_{di} 1.055	ρ_{df} 1.092
Height of soil particles $H_s = \frac{M_s \times 1000}{\rho_s \times A}$	mm	7.915	7.915
Voids ratio $e = \frac{H - H_s}{H_s}$		e_i 1.257	e_f 1.180
Degree of saturation $S = \frac{\rho_s w}{e}$		S_i 98.3	S_f 100

Applied pressure	Date and time of application of applied pressure	Incremental† deflection ΔH	Thickness of specimen, H $(H_i - \Delta H)$	% change thickness $\frac{H_i - H}{H_i}$	Height of voids $(H - H_s)$	Voids ratio $\frac{(H - H_s)}{H_s}$
kPa		mm	mm	%	mm	
25		0.089	17.771			1.245
50		0.045	17.726			1.240
100		0.061	17.665			1.232
200		0.088	17.577			1.221
400		0.110	17.467			1.207
800		0.159	17.308			1.187
1600		0.227	17.081			1.158
400		-0.060	17.141			1.166
100		-0.067	17.208			1.174
25		-0.048	17.256			1.180

* Delete the inappropriate words.
† Corrected where necessary for the compression of apparatus.



APPENDIX 6: Back-analysis of ultimate settlement and associated piezometric head drop

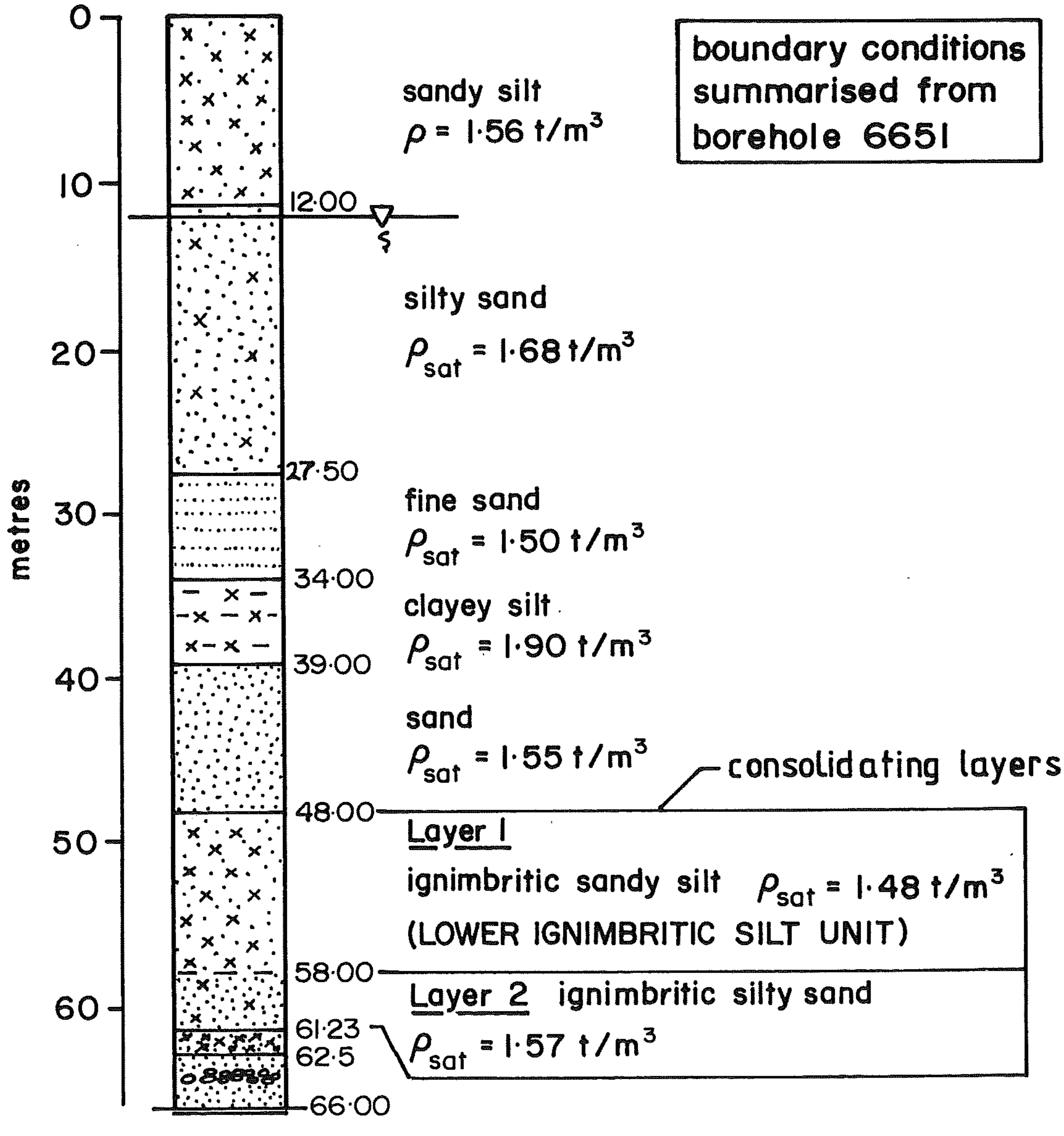


Figure A6·1: Analysis boundary conditions

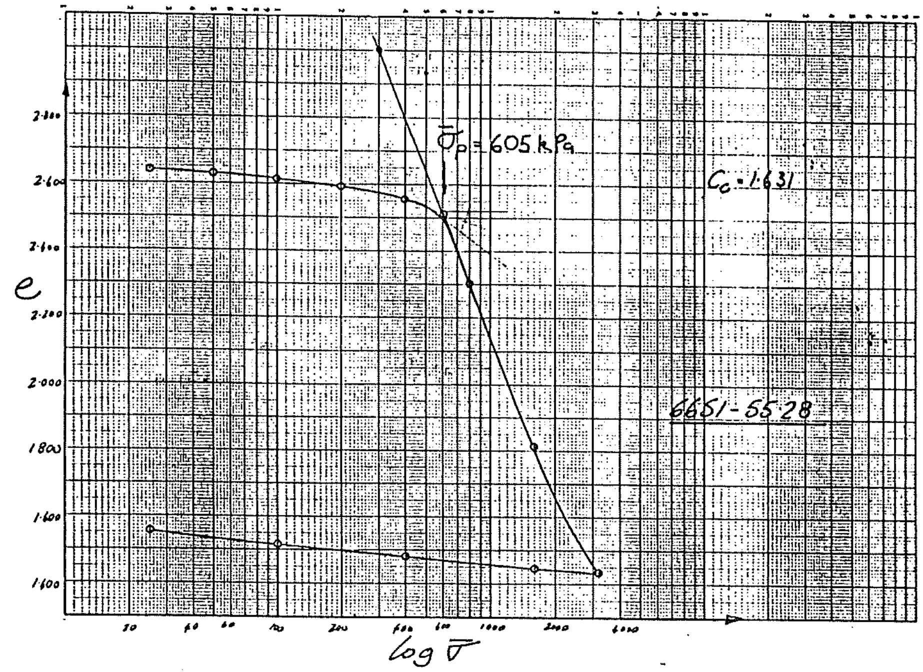


Figure A 6.2: e-log σ plot for 6651 - 55.28m (representative of layer 1).

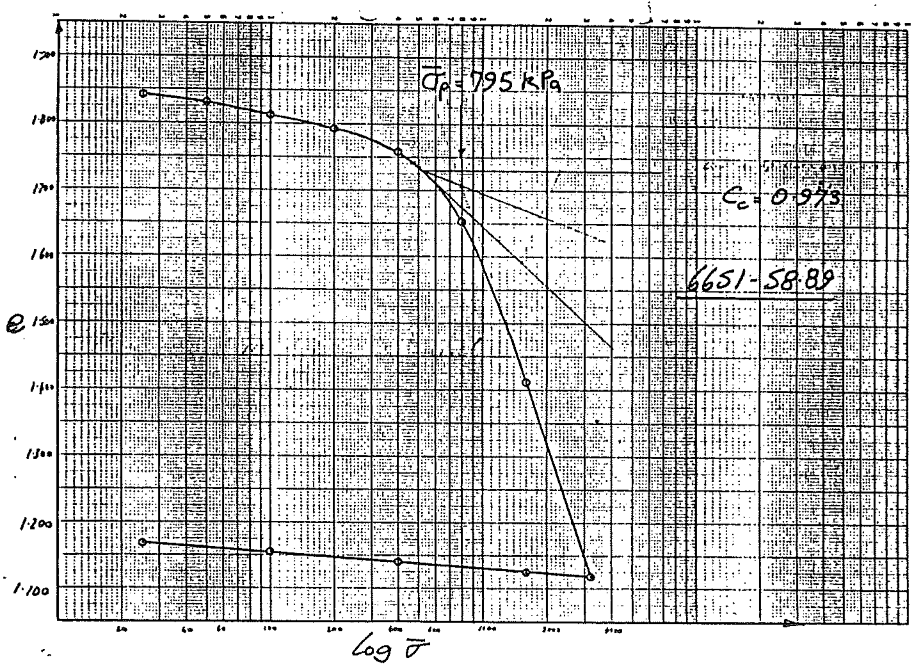


Figure A 6.3: e-log σ plot for 6651 - 58.89m (representative of layer 2).

1.0 Assumptions

- layers 1 and 2 (Figure A6.1) were normally consolidated prior to the hostel subsidence
- the e-log $\bar{\sigma}$ plots for BH6651 - 55.28m and 6651 - 58.89m (Figures A6.2 and A6.3) are representative of layers 1 and 2
- consolidation is restricted to layers 1 and 2 (adjacent materials are relatively incompressible) and is one-dimensional
- maximum past $\bar{\sigma}$ is defined by $\bar{\sigma}_\rho$ as measured by oedometer tests for each layer
- maximum past σ is due to dewatering.

Note: The subscripts '$_0$' and 'c' represent initial and consolidated conditions respectively.

$\bar{\sigma}_\rho$ = preconsolidation pressure

2.0 Calculations

2.1 For layer 1 (ignimbritic silt)

i) Initial effective stress at mid-height of layer 1

$$\bar{\sigma}_0 = 764.79\text{kPa} + 5\text{m}.1.48\text{tm}^{-3}.9.81\text{ms}^{-2} - 395.34\text{kPa} = 442.04\text{kPa}$$

ii) Initial void ratio at mid-height of layer 1

from e-log $\bar{\sigma}$ curve for 6651 - 55.28m (Figure A6.2) and boundary conditions

$\bar{\sigma}_c$ (= $\bar{\sigma}_\rho$) = 605 kPa $\rightarrow$ e_c = 2.512

C_c = 1.631 $\quad\quad$ H_c = 10.0m

since $e_c = e_0 - C_c \log\left(\frac{\bar{\sigma}c}{\bar{\sigma}_0}\right) \rightarrow e_0 = e_c + Cc \log\left(\frac{\bar{\sigma}c}{\bar{\sigma}_0}\right)$

$$\rightarrow e_0 = 2.734$$

iii) Original height of layer 1

since $H_c = H_0 \left(\frac{1 + e_c}{1 + e_0}\right) \rightarrow H_0 = \frac{H_c}{\left(\frac{1 + e_c}{1 + e_0}\right)}$

$\rightarrow H_0 = 10.632\text{m}$

for layer 1, 632mm of calculated settlement from

$\bar{\sigma}_0$ to $\bar{\sigma}_\rho$

Check of $\bar{\sigma}_0$

$\bar{\sigma}_0$ is calculated in (i) on the basis of 'consolidated' conditions. Since $\rho_{sat_0} < \rho_{sat_c}$, we need to consider $\bar{\sigma}_0$ on the basis of calculated e_0.

For $e_0 = 2.734$

$\rho_{sat} = 1.45 \text{ t.m}^{-3}$ (from oedometer test data)

$\rightarrow \bar{\sigma}_0 = 441.98$ kPa

which is not significant over previously calculated

$\bar{\sigma}_0 = 442.04$ kPa

iv) Find Δh_p, the drop of piezometric head

assuming no change of σ,

$\Delta\mu = \bar{\sigma}_c - \bar{\sigma}_0 = 605 \text{ kPa} - 442.04 \text{ kPa} = 162.96 \text{ kPa}$

$\mu_c = \mu_0 - \Delta\mu = 398.48 \text{ kPa} - 162.96 \text{ kPa} = 235.52 \text{ kPa}$

$h_c = \frac{\mu_c}{\rho_w g} = 24.01\text{m}$

$\Delta hp = h_0 - h_c = 40.62\text{m} - 24.01\text{m} = 16.61\text{m}$

to get 632mm of settlement from consolidation of layer 1, the piezometric head at the mid-height of the layer has to drop 16.61m.

2.2 For layer 2 (ignimbritic silty sand)

i) Initial effective stress at mid-height of layer 2

$$\bar{\sigma}_0 = 909.98\text{kPa} + 1.63\text{m}.\ 1.57\text{tm}^{-3}.9.81\text{ms}^{-2} - 460.38\text{kPa} = 474.70\text{kPa}$$

ii) Initial void ratio at mid height of layer 2

from e-log $\bar{\sigma}$ curve for 6651 - 58.89m (Figure A6.3) and boundary conditions

$\bar{\sigma}_c = (\bar{\sigma}_p) = 795$ kPa $\rightarrow$ $e_c = 1.708$

$C_c = 0.973$ $\quad\quad$ $H_c = 3.25$m

from 2.1 - ii) $\quad e_0 = 1.708 + 0.973.\log\left(\frac{795\text{kPa}}{474.70\text{kPa}}\right) = 1.926$

iii) Original height of layer 2

from 2.1 - iii) $\quad H_0 = \dfrac{3.25\text{m}}{\left(\frac{1 + 1.708}{1 + 1.926}\right)} = 3.512$

for layer 2, 262mm of calculated settlement from $\bar{\sigma}_0$ to $\bar{\sigma}_p$.

iv) Find Δhp, the drop of piezometric head

assuming no change of σ,

$\Delta\mu = \bar{\sigma}_c - \bar{\sigma}_0 = 795$ kPa $- 474.70$ kPa $= 320.30$ kPa

$\mu_c = \mu_0 - \Delta\mu = 461.66$ kPa $- 320.30$ kPa $= 141.36$ kPa

$$h_c = \frac{\mu_c}{\rho_w g} = 14.41\text{m}$$

$$\Delta h_\rho = h_0 - h_c = 47.06\text{m} - 14.41\text{m} = 32.65\text{m}$$

to get 262mm of settlement from consolidation of layer 2, the piezometric head at the mid-height of the layer has to drop 14.41m.

The calculated ultimate settlement due to consolidation of the ignimbritic silt and underlying silty sand is 894mm.

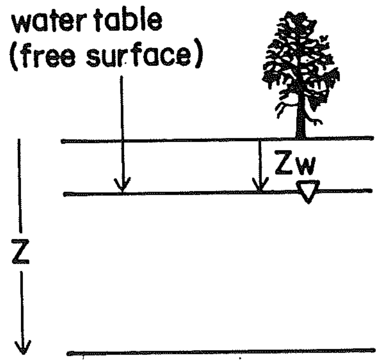
APPENDIX 7 : Theoretical basis and computer program for finite difference settlement-time analysis.

1.0 Introduction

The theoretical basis for this analysis was developed by Drs R O Davis and B W Hunt of the Civil Engineering Department, University of Canterbury. This study used the theoretical basis to develop DECONS, a Basic computer program for the finite difference solution.

2.0 Theoretical basis

2.1 Preliminary relationships



Consider a saturated soil layer being drained from its base

i) Darcys Law: $V = -k \dfrac{\partial h}{\partial z}$

where V = superficial velocity (which is not the velocity of the free surface)

h = total head

ii) Continuity Equation: $\dfrac{\partial e}{\partial t} = -(1 + e_0) \dfrac{\partial V}{\partial z}$

(from Darcys Law) $= k \ (1 + e_0) \dfrac{\partial^2 h}{\partial z^2}$ ....(1)

iii) Constitutive Relationship

The constitutive relationship relates $\bar{\sigma}$ to e. In this case the coefficient of compressibility (a_v) is used

$$a_v = \frac{-de}{d\bar{\sigma}}$$

For finite difference development

$e - e_0 = a_v (\bar{\sigma}_0 - \bar{\sigma})$ is assumed

$$\rightarrow \quad \frac{\partial e}{\partial t} = -a_v \frac{\partial \bar{\sigma}}{\partial t}$$

iv) The Effective Stress Principal

$$\bar{\sigma} = \sigma - \mu$$

here $\sigma = \int_0^z \rho g . dz$ which is not constant because ρ changes.

Therefore $\frac{\partial \bar{\sigma}}{\partial t} = \frac{\partial \sigma}{\partial t} - \frac{\partial \mu}{\partial t}$

$$\rightarrow \quad \frac{\partial e}{\partial t} = -a_v\left(\frac{\partial \sigma}{\partial t} - \frac{\partial \mu}{\partial t}\right) \quad ....(2)$$

- For $\frac{\partial \sigma}{\partial t}$, $\sigma\ (t_0) = \rho_d g z_w + \rho_{sat} g\ (z-z_w)$

for $t_0 = 0$

$$\sigma\ (t_0 + \Delta t) = \rho_d g\ (z_w + \frac{dz_w}{dt} . dt) + \rho_{sat} g\ (z-z_w - \frac{dz_w}{dt} . dt)$$

where Δt = finite time step

$$= \sigma(t_0) + \frac{dz_w}{dt} . dt\ (\rho_d g - \rho_{sat} g)$$

$$= \sigma\ (t_0) - \frac{\rho_w ge}{1+e} . \frac{dz_w}{dt} . dt$$

$$\rightarrow \quad \frac{d\sigma}{dt} = \frac{\sigma(t_0 + \Delta t) - \sigma(t_0)}{dt} = \frac{-\rho_w ge}{1+e} . \frac{dz_w}{dt}$$

Now $\frac{dz_w}{dt}$ = velocity of free surface $= \frac{V}{n} = \frac{V}{e/(1+e)}$

Hence $\boxed{\frac{d\sigma}{dt} = -\rho_w gV \text{ evaluated at } z = z_w}$ ....(3)

So if the superficial velocity of the free surface is known, we can find $\frac{\partial \sigma}{\partial t}$

- For $\frac{\partial \mu}{\partial t}$, for any $z > z_w$ we have $h = h_e + h_p$

where h_e = elevation head

h_p = pressure head

$= h_e + \frac{\mu}{\rho_w g}$

$\rightarrow \mu = \rho_w g\,(h - h_e)$

$$\rightarrow \boxed{\frac{\partial \mu}{\partial t} = \rho_w g \frac{\partial h}{\partial t}} \quad \ldots\ldots \quad (4)$$

v) Deriving an expression for change of total head with time $\frac{\partial h}{\partial t}$

Equation (2), $\frac{\partial e}{\partial t} = -a_v\left(\frac{\partial \sigma}{\partial t} - \frac{\partial \mu}{\partial t}\right)$

$= -a_v(-\rho_w g V - \rho_w g \frac{\partial h}{\partial t})$ from equations 3 and 4

$= \rho_w g a_v\left(\frac{\partial h}{\partial t} + V\right)$

And using this in equation (1) gives

$$\boxed{\frac{\partial h}{\partial t} + V = \frac{k\ (1 + e)}{\rho_w g a_v} \frac{\partial^2 h}{\partial z^2}} \quad \ldots\ldots \quad (5)$$

Initial conditions within the layer $h = h^\circ$ = constant everywhere.

Boundary conditions are $h = 0$ at bottom (which is fixed)

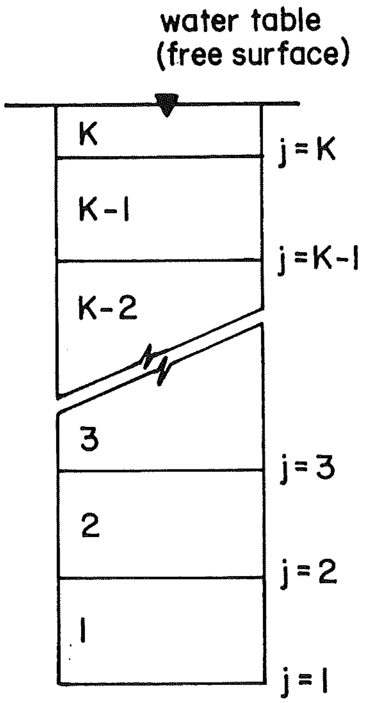
and $h = h_e$ at top (which moves with velocity $V/_n$

Note: The V term (equation 5) enters because we assume the density changes from ρ_{sat} to ρ_d as the water table falls. In fact, the density change will probably not be so dramatic because of capillary water retained in soil pores. Because of the capillary effect $\frac{\partial \sigma}{\partial t}$ is assumed to be small and the V term is omitted.

2.2 Derivation of finite difference representation

i) Finite difference mesh:

Consider a saturated soil profile, divided into zones (finite elements) numbered from the base:



- At any time t, the uppermost zone to be considered will be the <u>last</u> complete zone before the water table is reached.

- If during some time increment Δt the water table moves into a new zone, then that zone will no longer be used for the remainder of the solution.

- Assume that a_v = constant.

ii) Conservation of pore fluid mass.

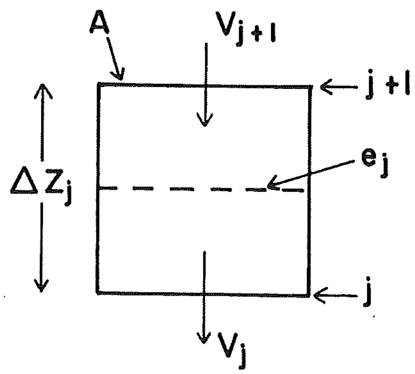
- Consider j, a typical zone:

Let Δz_j = zone height

v_j = pore fluid velocity (downward velocities positive)

e_j = void ratio at zone mid-height

A = zone sectional area (constant)



- Zone volume, $\bar{V} = A\Delta z_j$

but $\bar{V} = \bar{V}_s + \bar{V}_v$ where $\bar{V}_s$ = volume of solids

$\bar{V}_v$ = volume of voids

$$= \bar{V}_s\,(1 + e_j)$$

$$\rightarrow \quad A\Delta z_j = \bar{V}_s\,(1 + e_j)$$

- since soil solids are incompressible, $\bar{V}_s$ is a constant and not a function of time.

- therefore $\frac{A\Delta z_j}{1+e_j}$ is not dependent on time

so $\frac{\Delta z_j}{1+e_j} = \frac{\Delta z_j^\circ}{1+e_j^\circ}$ where Δz_j° and e_j° are initial values at time $t = 0$

- Mass of pore fluid $= \rho_w \bar{V}_v$ where ρ_w = density of water

$$= \frac{\rho_w \Delta z A e_j}{1+e_j}$$

the conservation of pore fluid mass requires that

change of mass = mass flowing in top - mass flowing out of base

$$\rightarrow \frac{\partial}{\partial t} \frac{\rho_w \Delta z_j A e_j}{1+e_j} = \rho_w V_{j+1} A - \rho_w V_j A$$

(this time derivative has a negative value since pore fluid mass decreases with time).

since $\rho_w A$ = constant

$$\rightarrow \frac{\partial}{\partial t} \frac{\Delta z_j e_j}{1+e_j} = V_{j+1} - V_j$$

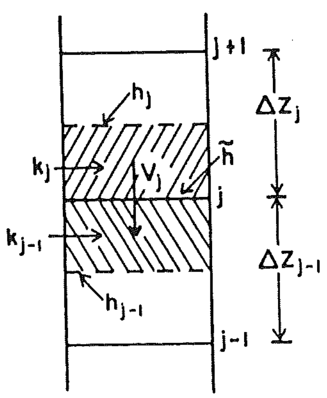
$$\rightarrow \boxed{\frac{\partial e_j}{\partial t} = \frac{1+e_j^\circ}{\Delta z_j^\circ} V_{j+1} - V_j}$$

The Mass Balance Equation ...... (6)

iii) Darcys Law

- Darcys Law, $V = -k \frac{\partial h}{\partial z}$ where h = total head in direction of flow ($h = h_e + h_p$)

- For finite difference solution



- define h_j at the centre of the zone
- let $\tilde{h}$ represent the total head at line j
- k_j, k_{j-1} = zone permeabilities

Then $V_j = k_j \cdot \frac{h_j - \bar{h}}{\frac{1}{2}\Delta z_j} = k_{j-1} \cdot \frac{\bar{h} - h_{j-1}}{\frac{1}{2}\Delta z_{j-1}}$

since velocity above j = velocity below j

Combine to eliminate $\bar{h}$

$$\rightarrow \boxed{V_j = \frac{2k_{j-1}\, k_j\, (h_j - h_{j-1})}{\Delta Z_{j-1}\, k_j + \Delta Z_j k_{j-1}}}$$

Darcys Law in Finite Difference Form .... (7)

iv) Constitutive relationship

$$\frac{\partial e}{\partial t} = -a_v \frac{\partial \sigma}{\partial t} = -a_v \left(\frac{\partial \sigma}{\partial t} - \frac{\partial \mu}{\partial t} \right) \qquad \text{(equation 2)}$$

since $\frac{\partial \sigma}{\partial t} = 0$ is assumed, (section 2.1 - v)

$$\rightarrow \quad \frac{\partial e}{\partial t} = \rho_w g a_v \frac{\partial h}{\partial t} \qquad \text{(from equation 4)}$$

$$\rightarrow \boxed{\frac{\partial e_j}{\partial t} = \rho_w g a_{v_j} \frac{\partial h_j}{\partial t}} \qquad \ldots\ldots\ (8)$$

v) Zone height

$$\boxed{\Delta Z_j = (1 + e_j) \frac{\Delta Z_j^\circ}{1+e_j}} \qquad \ldots\ldots\ (9)$$

vi) Initial solution conditions, t = 0

ΔZ_j° specified everywhere

e_j " "

$V_j = 0$ " "

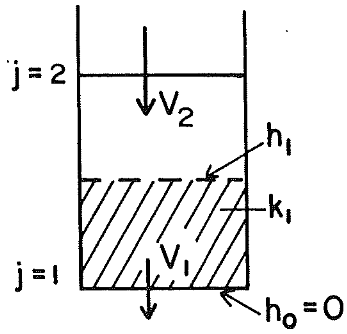
$h_j = H_0$ " "

$l = \frac{1}{2}\Delta Z_{K-1}$ where l is the distance to the free surface above the last complete zone.

vii) Boundary conditions

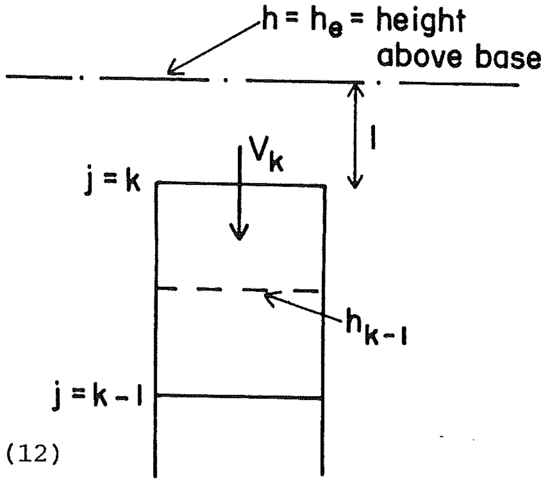
- Bottom boundary

for all $t>0$



$$V_1 = \frac{k_1 h_1}{\frac{1}{2}\Delta Z_1} \qquad \text{(from Darcys Law)} \quad \ldots\ldots\ (10)$$

- Upper boundary



to find h_e:

$$h_e = l + \sum_{j=1}^{K-1} \Delta Z_j \quad \ldots\ldots\ (11)$$

then Darcy's Law gives

$$V_K = \frac{k_{K-1}\, k_K\, (h_e - h_{K-1})}{\frac{1}{2}\Delta Z_{K-1}\, k_K + l\, k_{K-1}} \quad \ldots\ldots\ (12)$$

the velocity of the free surface is then given by

$$\frac{dl}{dt} = \frac{-V_K\,(1+e_K)}{e_K} \quad \ldots\ldots\ (13)$$

(this is the "pore velocity", $V/_n$)

3.0 Computer Program

3.1 Program approach

The logic steps followed by DECONS1 are as follows:

Let ^ mean evaluated at $t + \Delta t$

Steps

0:

$$\hat{l} = l - V_k (1 + e_k) \frac{\Delta t}{e_k} \quad \ldots\ldots\ldots \quad \text{(equ 13)}$$

check that $\hat{l} > 0$. If $\hat{l} < 0$, then set $K = K-1$

and $\hat{l} = \Delta Z_k + \hat{l}$

For $1 \leqslant j \leqslant K-1$:

1:

$$\hat{e} = e_j + (1 + e_j^\circ)(V_{j+1} - V_j) \frac{\Delta t}{\Delta Z_j^\circ} \quad \ldots\ldots\ldots \quad \text{(equ 6)}$$

2:

$$\Delta\hat{Z}_j = (1 + \hat{e}_j) \frac{\Delta Z_j^\circ}{1+e_j^\circ} \quad \ldots\ldots\ldots \quad \text{(equ 9)}$$

note: $\dfrac{\Delta Z_j^\circ}{1+e_j^\circ} = \dfrac{\Delta Z_j}{1+e_j}$ used in DECONS1

3:

$$\hat{h}_j = h_j + \frac{\hat{e} - e_j}{\rho_w g a_{v_j}} \quad \ldots\ldots\ldots \quad \text{(equ 8)}$$

4:

$$\hat{V}_j = \frac{2k_{j-1}k_j (\hat{h}_j - h_{j-1})}{\Delta\hat{Z}_{j-1}k_j + \Delta\hat{Z}_j k_{j-1}} \quad \ldots\ldots\ldots \quad \text{(equ 7)} \qquad \text{for } 2 \leqslant j \leqslant K-1$$

5:

At the lower boundary: $$\hat{V}_1 = \frac{k_1\hat{h}_1}{\frac{1}{2}\Delta\hat{Z}_1} \quad \ldots\ldots\ldots \quad \text{(equ 10)}$$

At the upper boundary: $$\hat{h}_e = \hat{l} + \sum_{j=1}^{k-1} \Delta\hat{Z}_j \quad \ldots\ldots\ldots \quad \text{(equ 11)}$$

$$\hat{V}_k = \frac{k_{k-1}k_k (\hat{h}_e - \hat{h}_{k-1})}{\frac{1}{2}\Delta\hat{Z}_{k-1}k_k + \hat{l}k_{k-1}} \quad \ldots\ldots \quad \text{(equ 12)}$$

Now everything updated at $t + \Delta t$

3.2 Numerical stability

The explicit finite difference technique used, because of possible numerical instability requires certain restrictions on input parameters. Criteria used for numerical stability is:

$$\frac{C_v \Delta t}{\Delta Z^2} < 0.5$$

Theoretical values of C_v are evaluated from the input data and numerical stability is tested by DECONS1 for each layer.

```
10 PRINT "DECONS.1 is a Basic Program representing one-dimensional "
20 PRINT "consolidation numerically. The program calculates settlement "
30 PRINT "plus changes in void ratio, total water head, superficial water "
40 PRINT "velocity and water table position for layered soils undergoing "
50 PRINT "drainage from the base. Maximum number of soil layers is 20."
60 PRINT "Maximum number of soil zones is 200. Adjust top layer subdivision "
70 PRINT "to allow initial water table position at half a zone height above "
80 PRINT "top of sequence. Layers are numbered from base of sequence. "
85 PRINT\PRINT
100 REM * ARRAY DIMENSIONS *
112 DIM E(200), Z(200), H(200), V(201), Rk(20), D(20), I(20), E1(20), K(20)
114 DIM Av(20), Cv(20), Z1(20), HS(200), Zo(200), I1(20)
116 DIM KJ(200)
120 REM *******************
122 REM *  INPUT DATA      *
124 REM *******************
130 PRINT "How many soil layers ";\ INPUT M
132 IF M<21 THEN 136
134 PRINT "Too many layers! Try again "\ GO TO 130
136 M9=M
140 N=0
141 X3=0
145 FOR L=1 TO M
150  PRINT "Layer  ";L;":"
155  PRINT "    Height in metres ";\ INPUT D(L)
160  PRINT "    Number of zones ";\ INPUT I(L)
170  PRINT "    Initial void ratio ";\ INPUT E1(L)
180  PRINT "    Permeability in m/s ";\ INPUT K(L)
190  PRINT "    Coeff. of compressibility in m^2/kN ";\ INPUT Av(L)
210  Cv(L)=K(L)*(1+E1(L))/(9.81*Av(L))
220  PRINT "    Coeff. of consolidation in m^2/s is "; Cv(L)
230  PRINT
240  N=N+I(L)
250 NEXT L
251 OPEN "CALC.LIS" FOR OUTPUT AS FILE#1% \ MARGIN#1%,132
252 N9=N
260 IF N<201 THEN 280
270 PRINT "Total zones exceed 200! Try again "\ GO TO 140
280 PRINT "Permeability of material at water table in m/s ";\ INPUT K9
285 PRINT "What is time increment in seconds ";\ INPUT T
290 PRINT\PRINT
300 PRINT "Echo input data and check for numerical stabilty "
302 PRINT "================================================= "
304 PRINT
310 PRINT " L  D  Z   Eo       K          Av          Cv  "
320 PRINT "-----------------------------------------------"
321 PRINT #1%, "Echo input data and check for numerical stability "
322 PRINT #1%,"************************************************"
323 PRINT #1%
324 PRINT #1%," L   D    Z    Eo       K          Av        Cv"
325 PRINT #1%,"================================================"
330 FOR L=M TO 1 STEP -1
340  PRINT L;D(L);I(L);E1(L);K(L);Av(L);Cv(L)
341 PRINT #1%,L;D(L);I(L);E1(L);K(L);Av(L);Cv(L)
350  Z1(L)=D(L)/I(L)
360  Rk(L)=Cv(L)*T/(Z1(L)^2)
370  IF Rk(L)>0.5 THEN 390
380 PRINT "Layer ";L;" numerically stable "\PRINT
381 PRINT #1%,"Layer ";L;" numerically stable "\PRINT #1%\GO TO 400
390 PRINT "Layer ";L;" numerically unstable"\ PRINT
391 PRINT #1%,"Layer ";L;" numerically unstable "\PRINT #1%
```

```
400 NEXT L
410 PRINT\PRINT
415 PRINT "Do you want to continue (Y/N)";\ INPUT A$
420 IF A$="Y" THEN 435
430 GO TO 130
435 PRINT\PRINT
436 PRINT #1%,"Initial conditions at t=0 "
437 PRINT #1%,"=============================="
438 PRINT #1%
440 REM **********************
442 REM * INITIAL CONDITIONS *
444 REM **********************
446 PRINT "Initial conditions at t=0"
448 PRINT "=========================" \ PRINT
449 N=N9 \ M=M9
450 LO=Z1(M)/2
455 N1=N+1\V(N1)=0
460 PRINT "Distance of water table above top of sequence, l=";LO;"m"
462 PRINT "Superficial water velocity at top boundary, V=";V(N1);" m/s "
464 IF X3=1 THEN 473
466 PRINT #1%,"Distance of water table above top of sequence, l=";LO;" m "
468 PRINT #1%,"Superficial water velocity at top boundary, V=";V(N1);" m/s "
473 PRINT #1%
475 PRINT\PRINT "  J  ","  E  ","  DZ ","  Ht ","  V  "
480 PRINT "-----","-----","-----","-----","-----"
482 IF X3=1 THEN 500
484 PRINT #1%,"  J  ","  E  ","  DZ ","  Ht ","  V  "
486 PRINT #1%,"=====","=====","=====","=====","====="
500 I1(1)=I(1)
510 IF M=1 THEN 550
520 FOR L=2 TO M
530  L1=L-1 \ I1(L)=I1(L1)+I(L)
540 NEXT L
550 TH=0
560 FOR L=1 TO M
570  TH=TH+D(L)
580 NEXT L
590 HE=TH+LO
600 L=1 \ YO=0
610 E1=(1) \ Z(1)=D(1)/I(1)
620 E(1)=E1(1) \ KJ(1)=K(1)
630 H(1)=HE \ V(1)=(K(1)*HE)/(0.5*Z(1))
640 YO=YO+Z(1)
650 FOR J=2 TO N
660  E(J)=E1(L) \ Z(J)=D(L)/I(L)
670  Zo(J)=Z(J) \ KJ(J)=K(L)
680  H(J)=HE \ V(J)=0
690 IF J=I1(L) THEN L=L+1
700  YO=YO+Z(J)
702 NEXT J
704 FOR J=N TO 1 STEP -1
706  PRINT J,E(J),Z(J),H(J),V(J)
707 IF X3=1 THEN 709
708 PRINT #1%,J,E(J),Z(J),H(J),V(J)
709 NEXT J
710 PRINT\PRINT
711 PRINT #1%\PRINT#1%
712 REM ***********************
714 REM * TIME MARCHING       *
716 REM *    PROCEDURE        *
718 REM ***********************
```

```
720 T1=0
730 S=0
740 PRINT "Target time in seconds ";\ INPUT T2 \PRINT
745 Y=0
750 T1=T1+T
752 PZ=Z(1)
760 IF T1<T2 THEN 790
761 PRINT #1%,"Solution at t=";T2;" seconds "
762 PRINT #1%,"================================ "
765 PRINT "Solution at t=";T2;"seconds"
767 PRINT "=============================="
769 PRINT
770 S=1 \ PRINT "   J   ","   E   ","  DZ  ","  Ht  ","   V   "
772 PRINT "------","------","------","------","------"
775 PRINT #1%,"   J   ","   E   ","  DZ  ","  Ht  ","   V "
776 PRINT #1%,"=====","=====","=====","=====","====="
790 E2=E(1)+((1+E(1))*(V(2)-V(1))*T)/Z(1)
800 Z(1)=((1+E2)*Z(1))/(1+E(1))
810 K1=K(1)
820 H1=H(1)+((E2-E(1))/(9.81*Av(1)))
830 V(1)=(K1*H1)/(0.5*Z(1))
840 E(1)=E2 \ H(1)=H1
842 YI=PZ-Z(1) \ Y=Y+YI
850 L=1
860 FOR J=2 TO N
862  PZ=Z(J)
870  J1=J-1 \ J2=J+1
880  E2=E(J)+((1+E(J))*(V(J2)-V(J))*T)/Z(J)
890  Z(J)=((1+E2)*Z(J))/(1+E(J))
900  K2=K(L)
910  H2=H(J)+((E2-E(J))/(9.81*Av(L)))
920  V(J)=(2*K1*K2*(H2-H1))/((K2*Z(J1))+(K1*Z(J)))
930  E(J)=E2 \ K1=K2 \ H1=H2 \ H(J)=H1
932  YI=PZ-Z(J) \ Y=Y+YI
940  IF J=I1(L) THEN L=L+1
950 NEXT J
960 REM * TOP BOUNDARY CONDITION *
970 V(N1)=(K(M)*K9*(HE-H(N)))/((0.5*Z(N)*K(M))+(LO*K(M)))
980 L1=LO-(V(N1)*(1+E(N))*T/E(N))
982 LO=L1
984 IF LO>0 THEN 1000
986  L2=Z(N)+L1
988  LO=L2
990  N1=N1-1 \ N=N-1
992  K9=KJ(N1)
1000 ST=0
1010 FOR J=1 TO N
1020  ST=ST+Z(J)
1030 NEXT J
1040 HE=ST+LO
1044 FOR J=1 TO N
1046  IF Z(J)=Zo(J) THEN H(J)=HE
1048 NEXT J
1051 IF S=0 THEN 750
1060 FOR J=N TO 1 STEP -1
1070  PRINT J,E(J),Z(J),H(J),V(J)
1072 PRINT #1%,J,E(J),Z(J),H(J),V(J)
1080 NEXT J
1090 PRINT\PRINT "Velocity at sequence top is ";V(N1);"m/s"
1092 PRINT #1%
1093 PRINT #1%,"Pore water velocity at sequence top is ";V(N1);"m/s"
```

```
1100 PRINT "Consolidated sequence height ="; YO-Y; "m"
1101 PRINT #1%, "Consolidated sequence height = "; YO-Y; "m"
1102 PRINT "CHECK USING TH-Y "; TH-Y; "m"
1110 PRINT "Settlement ="; Y; "m"
1111 PRINT #1%, "Settlement ="; Y; "m"
1120 PRINT\PRINT
1125 X3=1
1130 PRINT "Any more calculations (Y/N)"; \ INPUT A$
1140 IF A$="Y" THEN 446
1145 CLOSE #1%
1150 END
```

APPENDIX 8: Representative calculations for settlement rate analysis using DECONS1 computer program.

Echo input data and check for numerical stability
****

L	D	Z	Eo	K	Av	Cv
8	12	3	1.167	.158E-04	.629E-04	.554877E-01

Layer 8 numerically stable

7	8.5	4	1.925	.255E-05	.000205	.370888E-02

Layer 7 numerically stable

6	3	3	.803	.17E-07	.000055	.568084E-04

Layer 6 numerically stable

5	9	3	1.532	.255E-05	.725E-04	.907814E-02

Layer 5 numerically stable

4	10	10	2.544	.117E-06	.00108	.391369E-04

Layer 4 numerically stable

3	3.23	3	1.742	.454E-06	.000366	.346715E-03

Layer 3 numerically stable

2	1.27	2	.8	.12E-08	.00003	.733945E-05

Layer 2 numerically stable

1	3.5	3	1.5	.255E-05	.000366	.177554E-02

Layer 1 numerically stable

Initial conditions at t=0
========================

Distance of water table above top of sequence, l= 2 m
Superficial water velocity at top boundary, V= 0 m/s

J	E	DZ	Ht	V
31	1.167	4	52.5	0
30	1.167	4	52.5	0
29	1.167	4	52.5	0
28	1.925	2.125	52.5	0
27	1.925	2.125	52.5	0
26	1.925	2.125	52.5	0
25	1.925	2.125	52.5	0
24	.803	1	52.5	0
23	.803	1	52.5	0
22	.803	1	52.5	0
21	1.532	3	52.5	0
20	1.532	3	52.5	0
19	1.532	3	52.5	0
18	2.544	1	52.5	0
17	2.544	1	52.5	0
16	2.544	1	52.5	0
15	2.544	1	52.5	0
14	2.544	1	52.5	0
13	2.544	1	52.5	0
12	2.544	1	52.5	0
11	2.544	1	52.5	0
10	2.544	1	52.5	0
9	2.544	1	52.5	0
8	1.742	1.07667	52.5	0
7	1.742	1.07667	52.5	0
6	1.742	1.07667	52.5	0
5	.8	.635	52.5	0
4	.8	.635	52.5	0
3	1.5	1.16667	52.5	0
2	1.5	1.16667	52.5	0
1	1.5	1.16667	52.5	.2295E-03

Solution at t= 1800 seconds

==========================

J	E	DZ	Ht	V
31	1.167	4	52.3495	0
30	1.167	4	52.3495	0
29	1.167	4	52.3495	0
28	1.925	2.125	52.3495	0
27	1.925	2.125	52.3495	0
26	1.925	2.125	52.3495	0
25	1.925	2.125	52.3495	0
24	.803	1	52.3495	0
23	.803	1	52.3495	0
22	.803	1	52.3495	0
21	1.532	3	52.3495	0
20	1.532	3	52.3495	0
19	1.532	3	52.3495	0
18	2.544	1	52.3495	0
17	2.544	1	52.3495	0
16	2.544	1	52.3495	0
15	2.544	1	52.3495	0
14	2.544	1	52.3495	0
13	2.544	1	52.3495	0
12	2.544	1	52.3495	0
11	2.544	1	52.3495	0
10	2.544	1	52.3495	0
9	2.544	1	52.3495	0
8	1.742	1.07667	52.3495	0
7	1.742	1.07667	52.3495	0
6	1.742	1.07667	52.3495	.760732E-12
5	.8	.635	52.3495	.699641E-09
4	.799862	.634952	51.98	.684283E-07
3	1.43311	1.13545	33.8611	.204986E-04
2	1.40054	1.12025	24.7947	.362367E-04
1	1.34404	1.09389	9.06272	.422529E-04

Pore water velocity at sequence top is 0 m/s
Consolidated sequence height = 50.3495 m
Settlement = .150459 m

Solution at t= 21600 seconds

===========================

J	E	DZ	Ht	V
31	1.167	4	52.2339	0
30	1.167	4	52.2339	0
29	1.167	4	52.2339	0
28	1.925	2.125	52.2339	0
27	1.925	2.125	52.2339	0
26	1.925	2.125	52.2339	0
25	1.925	2.125	52.2339	0
24	.803	1	52.2339	0
23	.803	1	52.2339	0
22	.803	1	52.2339	0
21	1.532	3	52.2339	0
20	1.532	3	52.2339	0
19	1.532	3	52.2339	0
18	2.544	1	52.2339	0
17	2.544	1	52.2339	0
16	2.544	1	52.2339	0
15	2.544	1	52.2339	0
14	2.544	1	52.2339	0
13	2.544	1	52.2339	0
12	2.544	1	52.2339	0
11	2.544	1	52.2339	0
10	2.544	1	52.2339	0
9	2.544	1	52.2339	.117531E-08
8	1.74197	1.07666	52.2275	.239194E-08
7	1.74195	1.07665	52.2218	.590515E-08
6	1.74186	1.07662	52.2078	.112923E-07
5	.799075	.634674	49.2082	.360343E-07
4	.793446	.632688	30.1797	.113831E-06
3	1.31206	1.07896	.147524	.13134E-06
2	1.31185	1.07886	.919542E-01	.14354E-06
1	1.31161	1.07875	.312281E-01	.147637E-06

Pore water velocity at sequence top is 0 m/s
Consolidated sequence height = 50.2339 m
Settlement = .266126 m

Solution at t= 86400 seconds

J	E	DZ	Ht	V
31	1.167	4	52.2288	0
30	1.167	4	52.2288	0
29	1.167	4	52.2288	0
28	1.925	2.125	52.2288	0
27	1.925	2.125	52.2288	0
26	1.925	2.125	52.2288	0
25	1.925	2.125	52.2288	0
24	.803	1	52.2288	0
23	.803	1	52.2288	0
22	.803	1	52.2288	0
21	1.532	3	52.2288	0
20	1.532	3	52.2288	0
19	1.532	3	52.2288	0
18	2.544	1	52.2288	0
17	2.544	1	52.2288	0
16	2.544	1	52.2288	0
15	2.544	1	52.2288	0
14	2.544	1	52.2288	0
13	2.544	1	52.2288	.742237E-09
12	2.54393	.999979	52.2225	.242588E-08
11	2.5437	.999914	52.2017	.496516E-08
10	2.54324	.999786	52.1593	.10013E-07
9	2.54233	.99953	52.0737	.209831E-07
8	1.741	1.07632	51.9592	.275136E-07
7	1.74077	1.07619	51.894	.356998E-07
6	1.74043	1.076	51.8094	.438925E-07
5	.796414	.633737	40.1672	.490089E-07
4	.788785	.63105	14.3398	.542653E-07
3	1.31175	1.07881	.599723E-01	.556265E-07
2	1.31165	1.07876	.364394E-01	.569762E-07
1	1.31155	1.07872	.123364E-01	.583244E-07

Pore water velocity at sequence top is 0 m/s
Consolidated sequence height = 50.2288 m
Settlement = .271205 m

Solution at t= .3456E+07 seconds

J	E	DZ	Ht	V
31	1.16693	3.99988	52.0665	.102014E-07
30	1.16693	3.99986	52.064	.108795E-07
29	1.16692	3.99986	52.0612	.117067E-07
28	1.92473	2.12478	52.0549	.12013E-07
27	1.9247	2.12476	52.0448	.123336E-07
26	1.92468	2.12473	52.0346	.126542E-07
25	1.92465	2.12471	52.024	.129734E-07
24	.802691	.999829	51.6371	.131058E-07
23	.802275	.999598	50.8664	.132439E-07
22	.80185	1	50.0875	.133841E-07
21	1.5302	2.99781	49.686	.138361E-07
20	1.53019	2.9978	49.6697	.14589E-07
19	1.53018	2.99778	49.6526	.151803E-07
18	2.51579	.991992	49.5793	.173935E-07
17	2.51408	.991534	49.4319	.199151E-07
16	2.51222	.990999	49.2631	.224385E-07
15	2.51014	.990402	49.0731	.249568E-07
14	2.50785	.98975	48.8619	.27483E-07
13	2.50536	.989041	48.6295	.300047E-07
12	2.50261	.988231	48.376	.325294E-07
11	2.49986	.987465	48.1014	.351482E-07
10	2.49673	.986602	47.8048	.378878E-07
9	2.49313	.985611	47.4855	.404143E-07
8	1.72417	1.0693	47.2677	.417776E-07
7	1.72386	1.06918	47.1693	.431259E-07
6	1.72339	1.06902	47.0677	.44491E-07
5	.794972	.633266	35.2759	.445782E-07
4	.788039	.630805	11.7967	.446657E-07
3	1.31184	1.07886	.475681E-01	.448568E-07
2	1.3117	1.07879	.285906E-01	.450131E-07
1	1.31154	1.07872	.954824E-02	.451426E-07

Pore water velocity at sequence top is .954552E-08 m/s
Consolidated sequence height = 50.091 m
Settlement = .409047 m

Solution at t= .432E+08 seconds

J	E	DZ	Ht	V
30	1.16549	3.99721	49.7167	.30112E-07
29	1.16548	3.9972	49.7091	.316573E-07
28	1.92011	2.12097	49.6919	.319213E-07
27	1.92006	2.12092	49.6654	.322431E-07
26	1.92	2.12087	49.6386	.32565E-07
25	1.91994	2.12082	49.6115	.328857E-07
24	.801072	.99893	48.6316	.330197E-07
23	.800025	.998348	46.6919	.331565E-07
22	.798971	1	44.7432	.332938E-07
21	1.52598	2.99274	43.7444	.338819E-07
20	1.52595	2.99271	43.7046	.343504E-07
19	1.52592	2.99267	43.6643	.348502E-07
18	2.45245	.973526	43.4989	.3513E-07
17	2.44923	.972622	43.2067	.35411E-07
16	2.44605	.971692	42.9125	.356862E-07
15	2.44286	.970761	42.6162	.359707E-07
14	2.43965	.969827	42.3179	.362469E-07
13	2.43643	.968906	42.0176	.365273E-07
12	2.43315	.967969	41.7153	.368025E-07
11	2.43009	.967108	41.4109	.370833E-07
10	2.42683	.966217	41.1045	.373588E-07
9	2.42334	.965254	40.7962	.376405E-07
8	1.70043	1.05977	40.597	.378333E-07
7	1.70015	1.05968	40.5087	.380203E-07
6	1.69973	1.05955	40.4199	.382125E-07
5	.793505	.632831	30.2995	.382998E-07
4	.787549	.630668	10.1362	.383867E-07
3	1.31182	1.07885	.409274E-01	.38578E-07
2	1.31169	1.07878	.246064E-01	.387346E-07
1	1.31153	1.07871	.822018E-02	.388638E-07

Pore water velocity at sequence top is .304496E-07 m/s
Consolidated sequence height = 49.8234 m
Settlement = .676571 m

chart to acc by Philip Ian Kelsey "An Engineering Geological Investigation of Ground Subsidence above the Huntly East Mine Area"

Legend to Figures 3·17 and 3·18

Material Symbols

Ignimbritic	Fluviatile	
c	c	–clay(ey)
z	z	–silt(y)
s	s	–sand(y)
	g	–gravel (ly)
		–peat and highly organic soils
		–coal

Particle Size (mm)		
fine (f)	medium (m)	coarse (c)
–	–	–
–	–	–
0·06–0·2	0·2–0·6	0·6–2·0
2–20	20–60	>60

Material Contacts

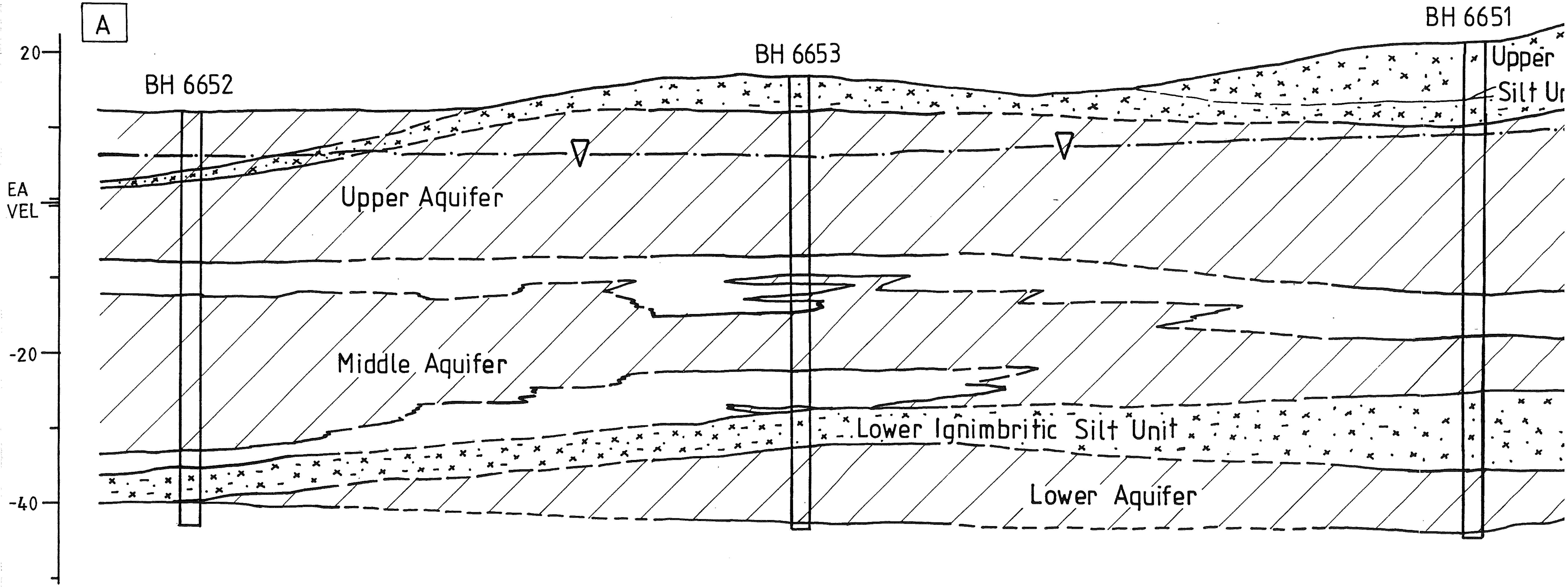
———— position approximate

— — — position inferred

Stratigraphy

Hn	Hinuera Formation	Tauranga Group
K-H	Hamilton-Kauroa Ashes	Tauranga Group
Kp	Karapiro Formation	Tauranga Group
Wg	Whangamarino Formation	Tauranga Group
W.C.M.	Waikato Coal Measures	Te Kuiti Group

diagram
"An Engi
Subsiden



GEOTECHNICAL INTERPRETATION

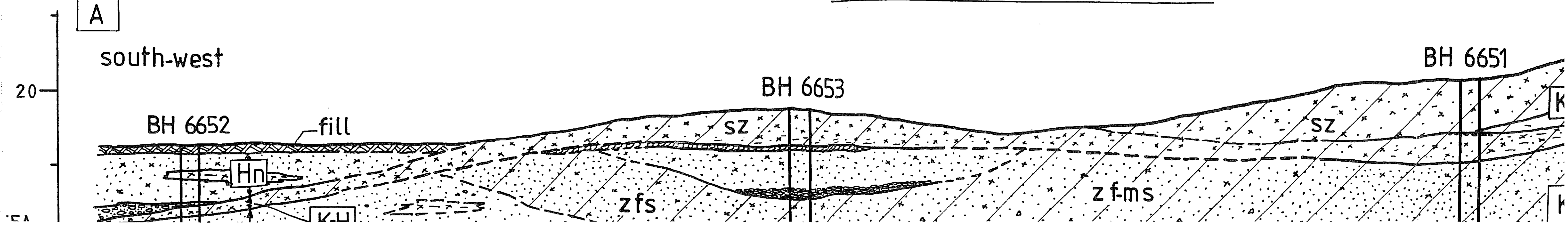
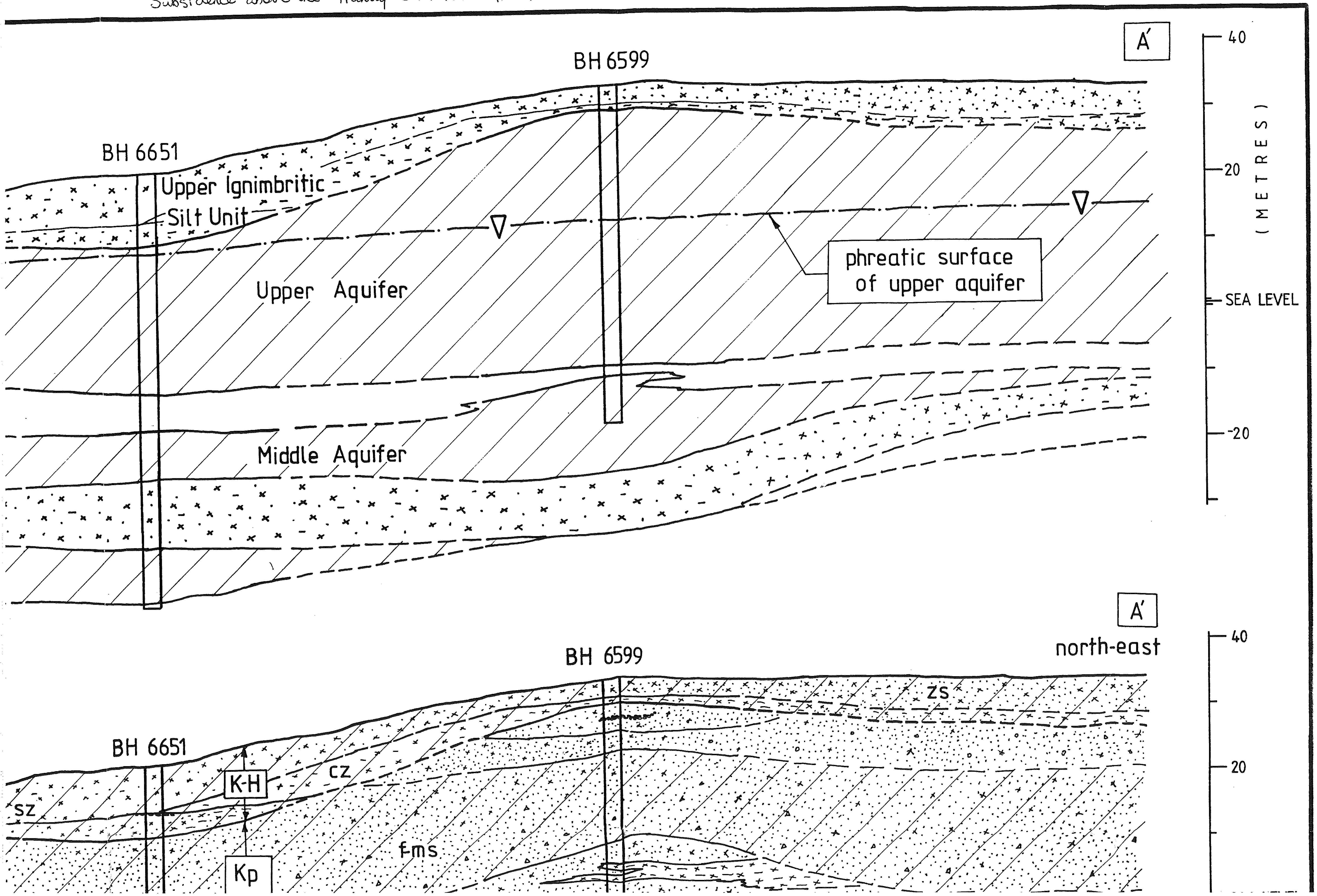
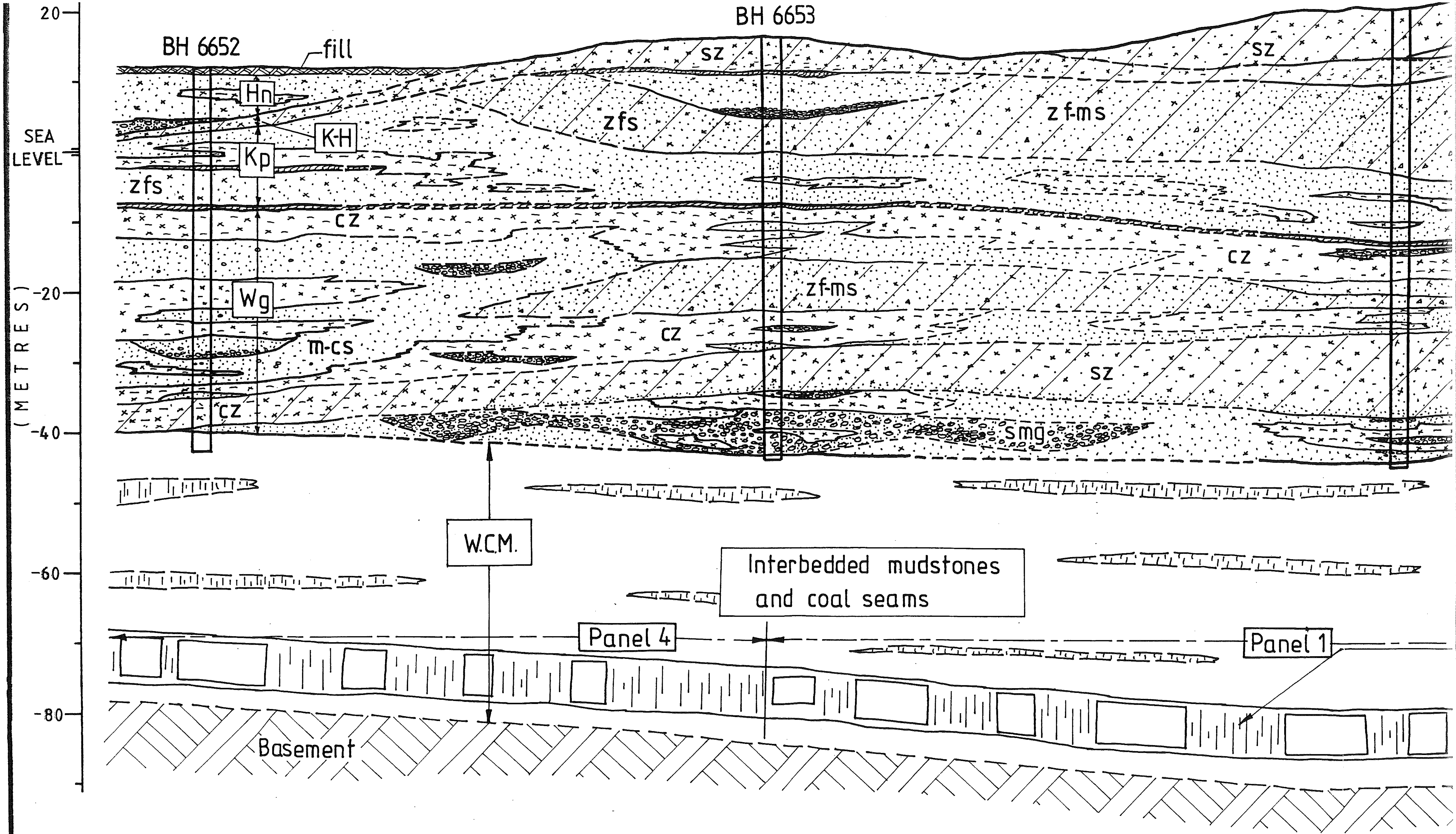


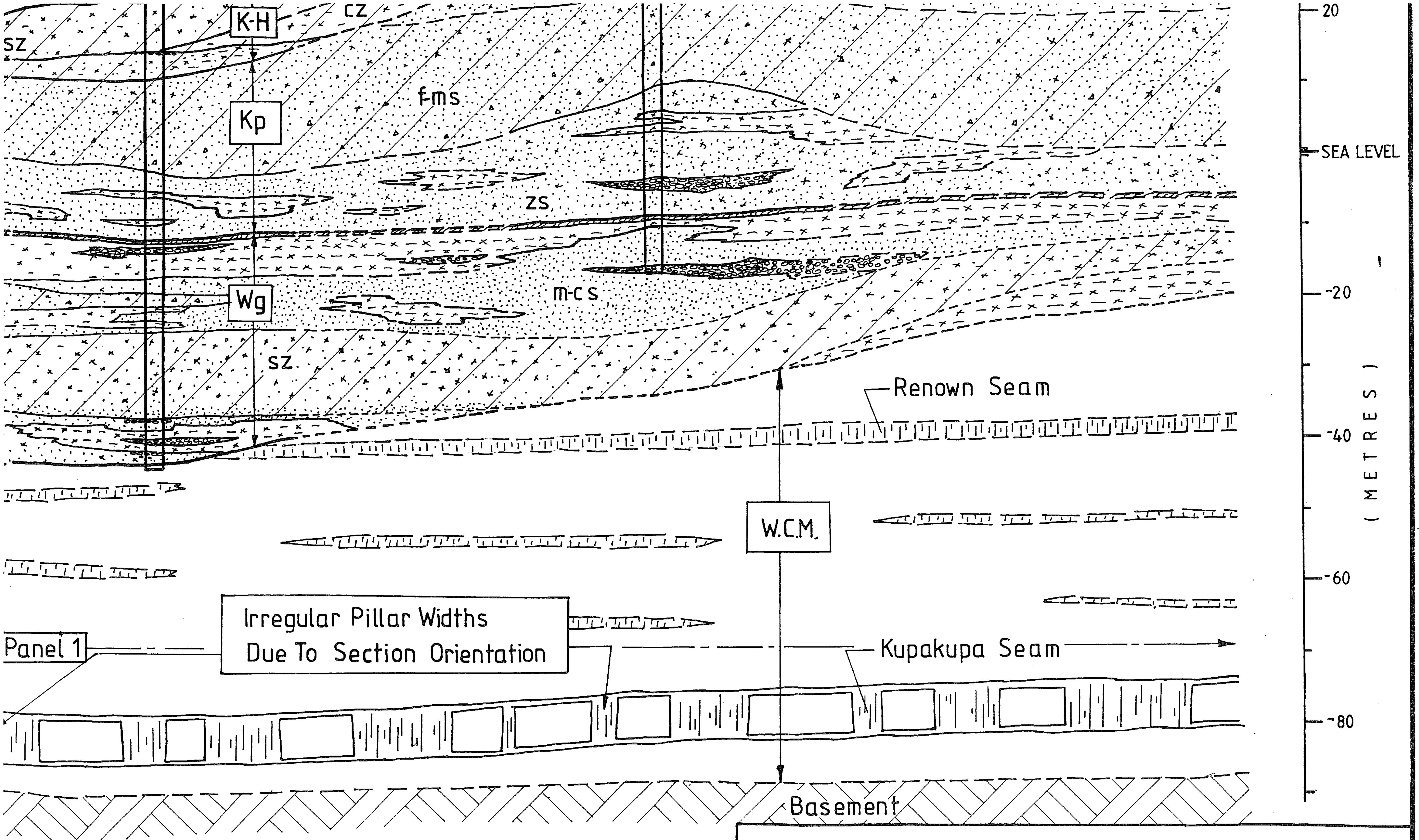
diagram to accompany thesis by Philip Ian Kelsey
"An Engineering Geological Investigation of Ground Subsidence above the Huntly East Mine Area."





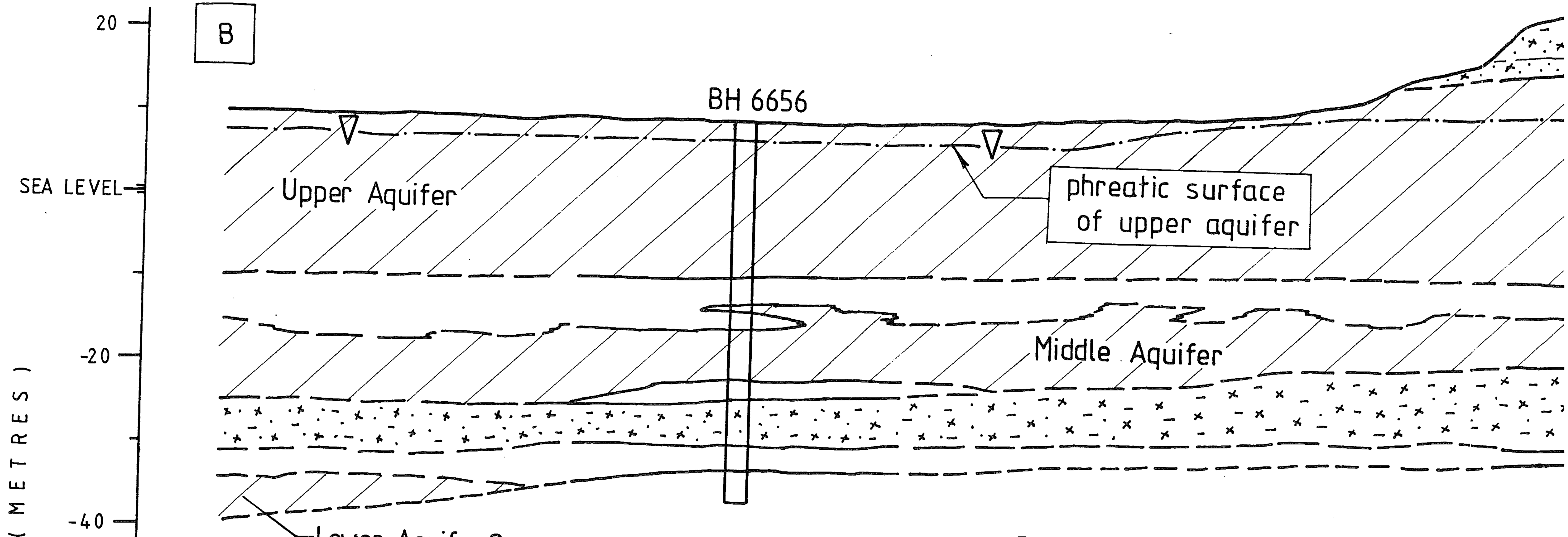
Horizontal Scale = Vertical Scale
(Original Scale 1:500)

GEOLOGICAL INTERPRETATION

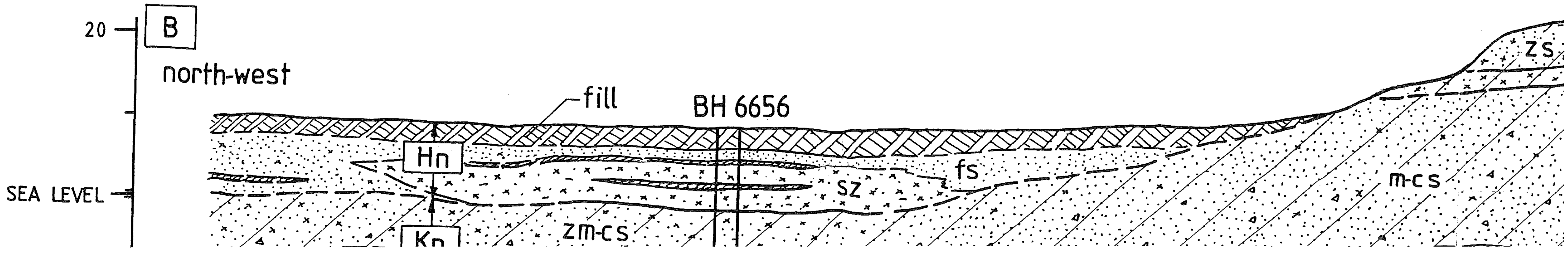


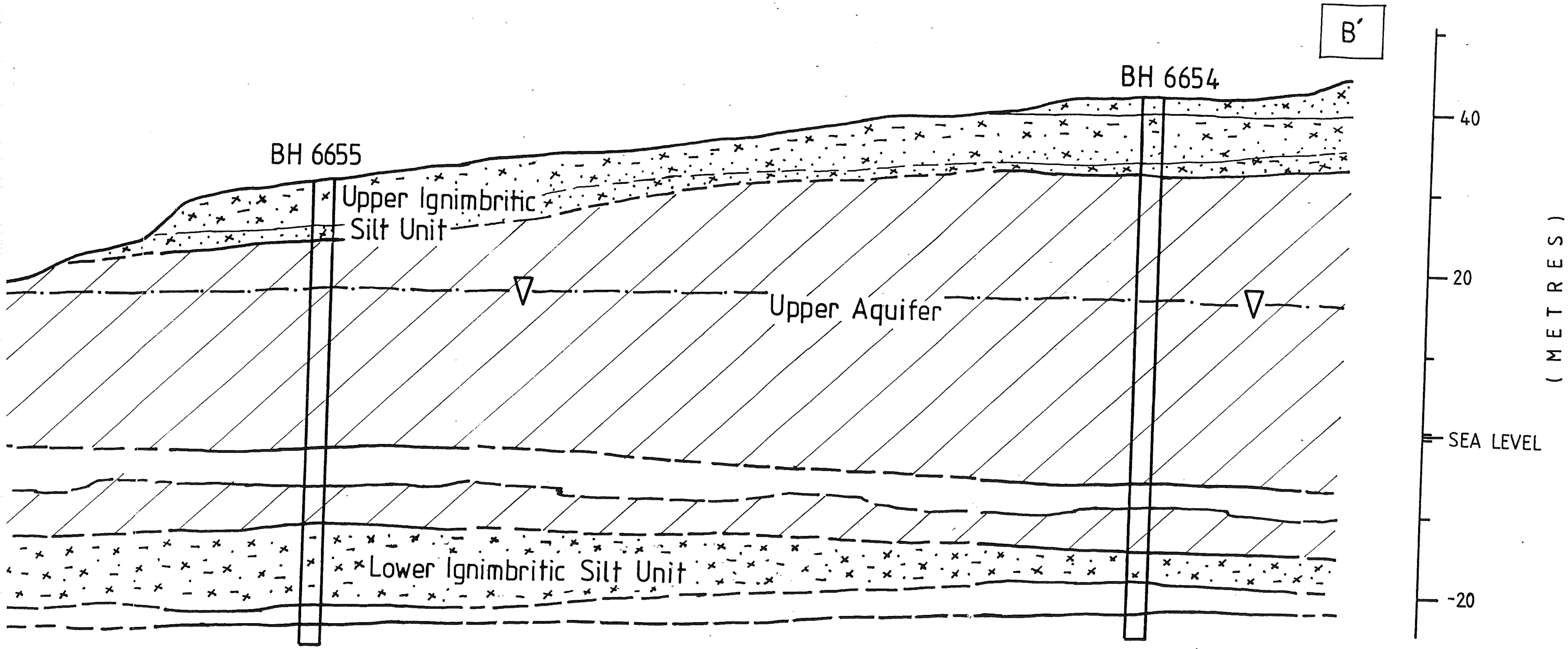
See Figure 3·19 for Section Location

Figure 3·17: Geological and Geotechnical Cross-sections for A–A′.

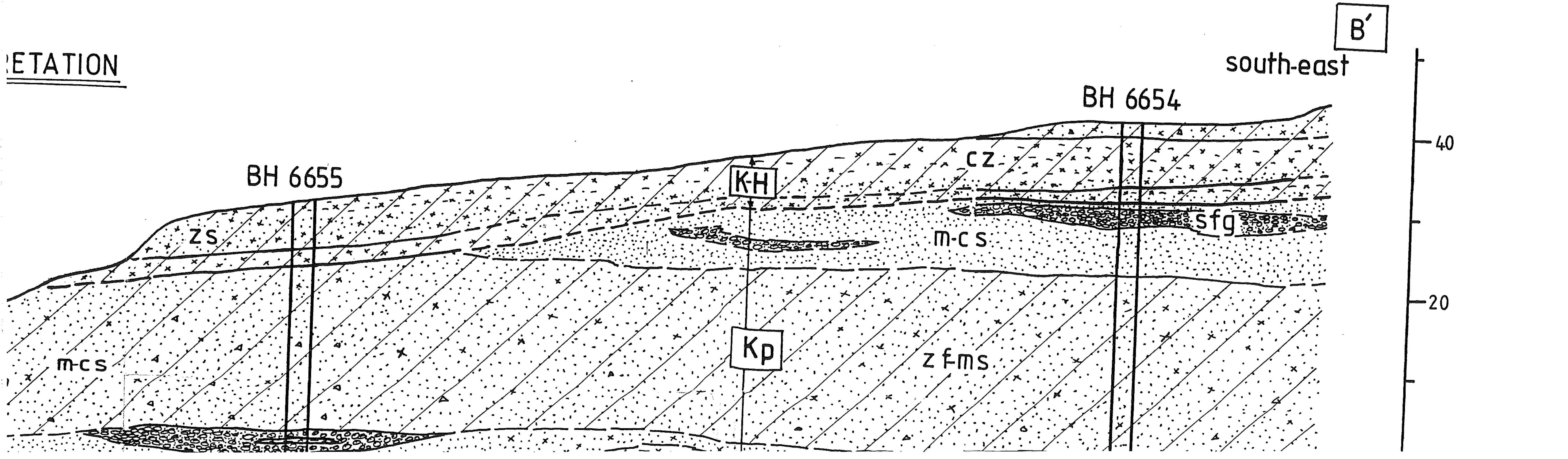


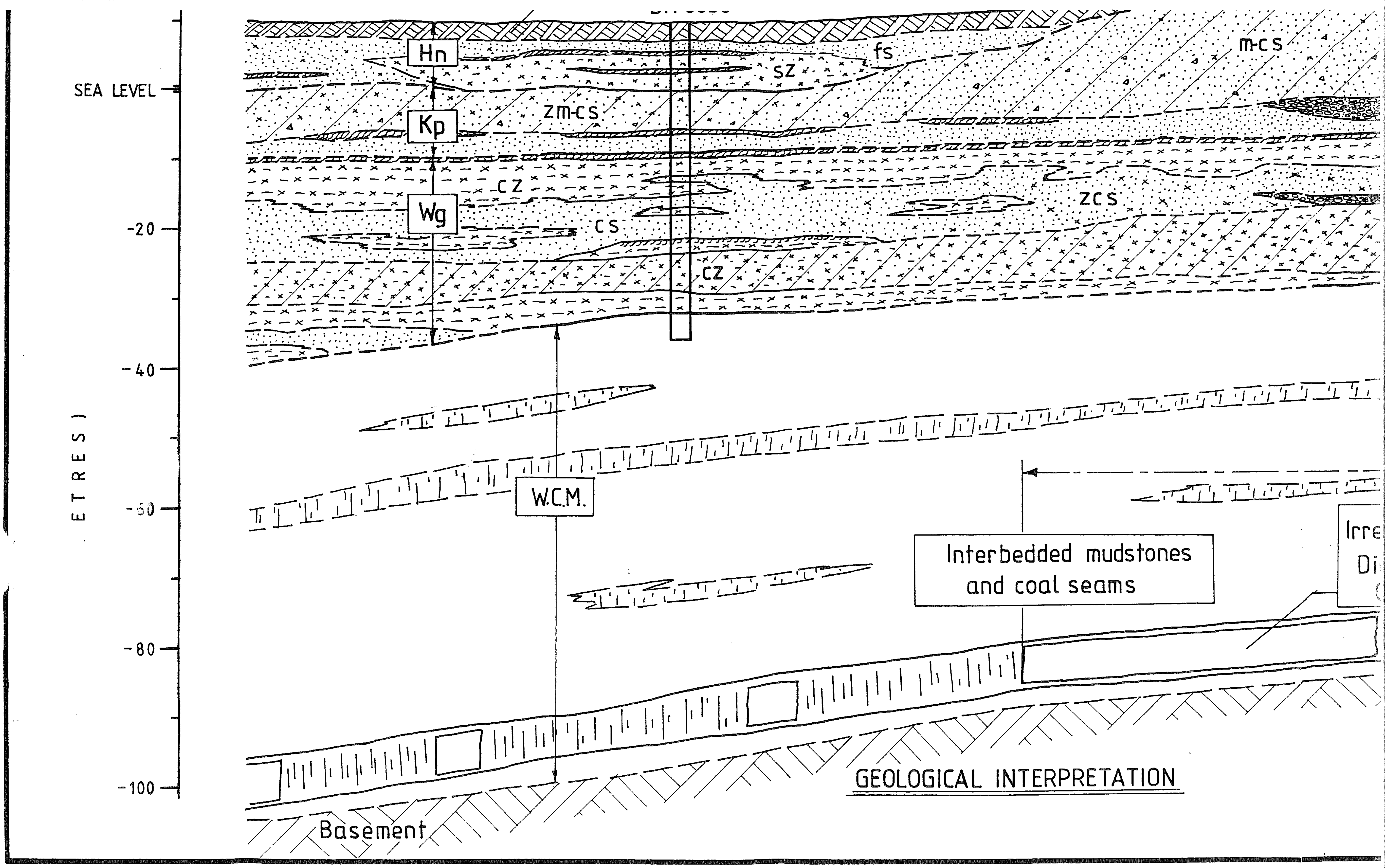
GEOTECHNICAL INTERPRETATION



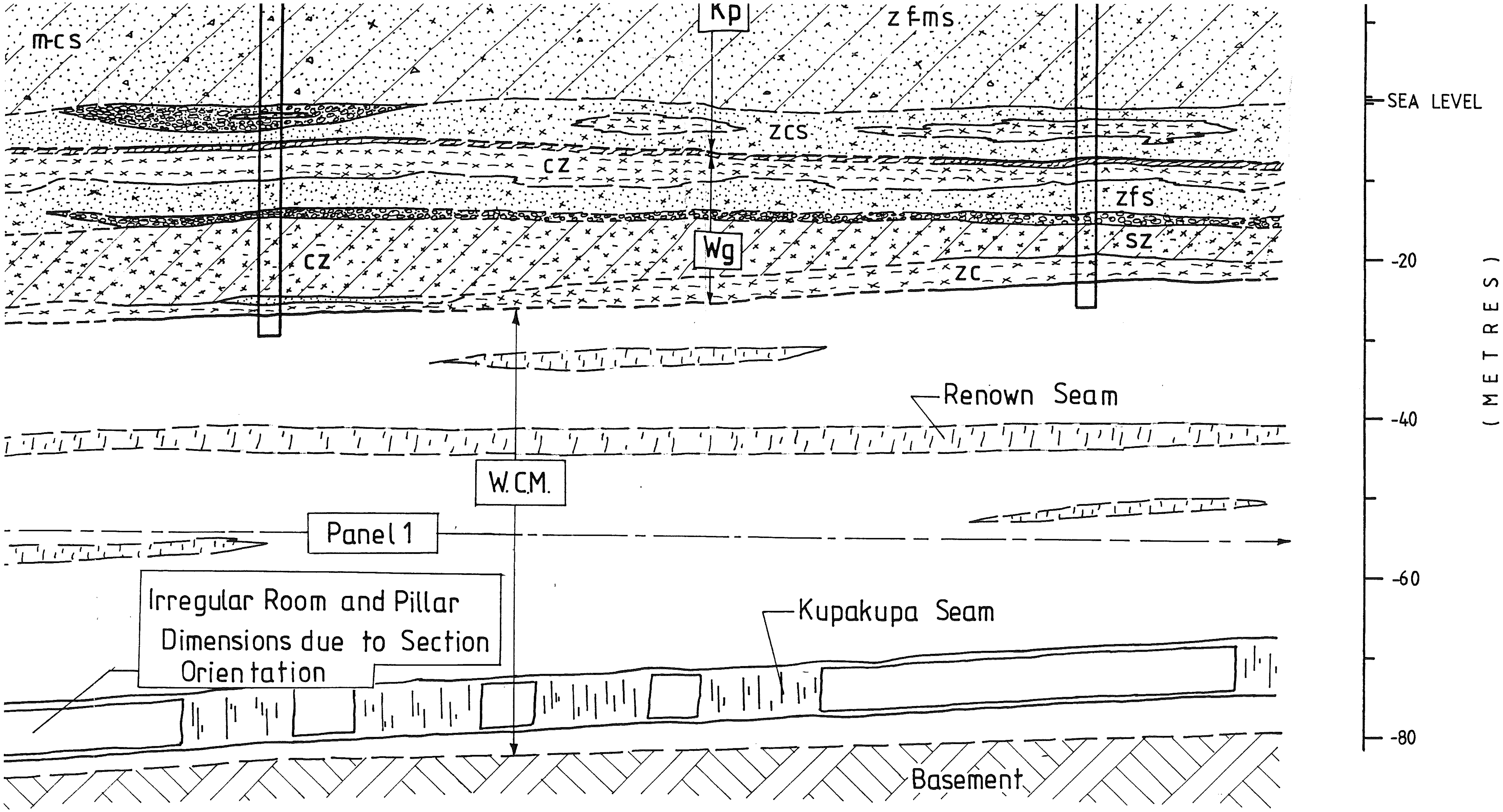

B′
BH 6654
BH 6655
Upper Ignimbritic
Silt Unit
Upper Aquifer
Lower Ignimbritic Silt Unit
40
20
SEA LEVEL
-20
(METRES)

ETATION


B′
south-east
BH 6654
BH 6655
cz
KH
sfg
zs
m-cs
Kp
zfms
m-cs
40
20


SEA LEVEL
-20
-40
-60
-80
-100
ETRES)
Hn
Kp
Wg
fs
sz
m-cs
zm-cs
cz
zcs
cs
cz
W.C.M.
Interbedded mudstones
and coal seams
Irre
Di
GEOLOGICAL INTERPRETATION
Basement

diac
"An
Sub



Horizontal Scale Vertical Scale
(Original Scale 1:500)
See Figure 3·19 for Section Location

Figure 3·18: Geological and Geotechnical Crosssections for B – B′

diagram to accompany thesis by Philip Ian Kelsey "An Engineering Geological Investigation of Ground Subsidence above the Huntly East Mine Area."